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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

EVALUATION OF THREE STANLEY HYDRAULIC ROCK DRILLS FOR USE BY DIVERS

February 1984

Prepared By
JOHN J. MCMULLEN ASSOCIATES, INC.
2021 Sperry Avenue
Ventura, CA 93003
(from an investigation conducted by NCEL)

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METRIC CONVERSION FACTORS

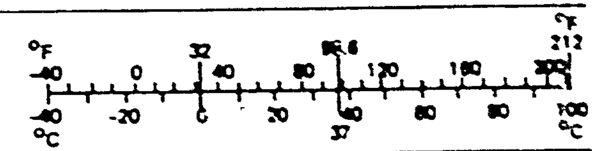
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Rock drills are often used in underwater construction projects to produce holes for installation of rock bolts or grouted fasteners and for placement of excavation explosives. Pneumatic rotary-percussion drills were originally used by the Navy underwater construction teams (UCTs), but were found to produce problems in the areas of operation,

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) reliability, and diver safety. Three commercially available hydraulic powered rock drills were selected for testing and evaluation with the objective of establishing their operating characteristics and suitability for use by Navy UCT's.

This report provides technical descriptions of the drills, describes the test and evaluation program and reports on the results, and addresses the hazard and safety aspects associated with the use of each device.

CONTENTS

TABLES

FIGURES

FIGURES (CONTD)

INTRODUCTION

Rock drills are often used in underwater construction projects to produce holes for installation of rock bolts or grouted fasteners and for placement of excavation explosives. Pneumatic rotary-percussion drills were originally used by the Navy underwater construction teams (UCT's), but problems in the areas of operation, reliability, and diver safety prompted the development of hydraulic powered units.

A hand-held, light duty underwater rock drill was developed by the Naval Civil Engineering Laboratory (NCEL), under the sponsorship of the Naval Facilities Engineering Command (NAVFAC), as reported in Reference 1. A second effort by NCEL, also sponsored by NAVFAC, resulted in the development of another prototype diver-operated rock drill. This development effort was reported in Reference 2. These drills were used successfully by the Navy underwater construction divers, but the number of prototypes developed by NCEL was insufficient to satisfy the increasing demand for these units.

It was decided that commercially manufactured tools would have certain advantages in meeting this demand. Commercial rock drills would be readily available for purchase and would use replacement parts which could be easily obtained. Three tools were selected for testing and evaluation with the objective of establishing their operating characteristics and suitability for use by Navy UCT's. The three test objects were:

- Hydraulic Hammer Drill, Model HD20, manufactured by Stanley Hydraulic Tools,

- Hydraulic Hammer Drill, Model HD45, manufactured by Stanley Hydraulic Tools, and

- Hydraulic Sinker Drill, Model SK58, Type 110, manufactured by Stanley Hydraulic Tools.

These units are illustrated in Figure 1.

This report provides technical descriptions of the drills, describes the test and evaluation program and reports on the results, and addresses the hazard and safety aspects associated with the use of each device.

BACKGROUND

Use of the Tools

The operations in which rock drills have been used have specific requirements for hole size. Holes for placement of explosives for excavation of seafloor rock and coral have diameters ranging from 1-1/2 to 4 inches. Rock bolts require hole diameters of less than 1 inch and up to 2-1/2 inches, depending on the hardness of the material being penetrated. The depths of these holes may be as great as 2 feet. Hole diameters ranging from 1-5/8 to 3 inches are required for grouted seafloor fasteners.

Earlier Developments

The pneumatic-powered sinker drills originally used by the Navy underwater construction divers created numerous problems. These included:

- Reduced visibility caused by the exhaust air bubbles.

- Nausea, difficulty in breathing and ear squeeze caused by percussive action of the exhaust air.

- Difficulty in locating holes without the use of a template.

- High maintenance requirements resulting from seawater entering the exhaust port.

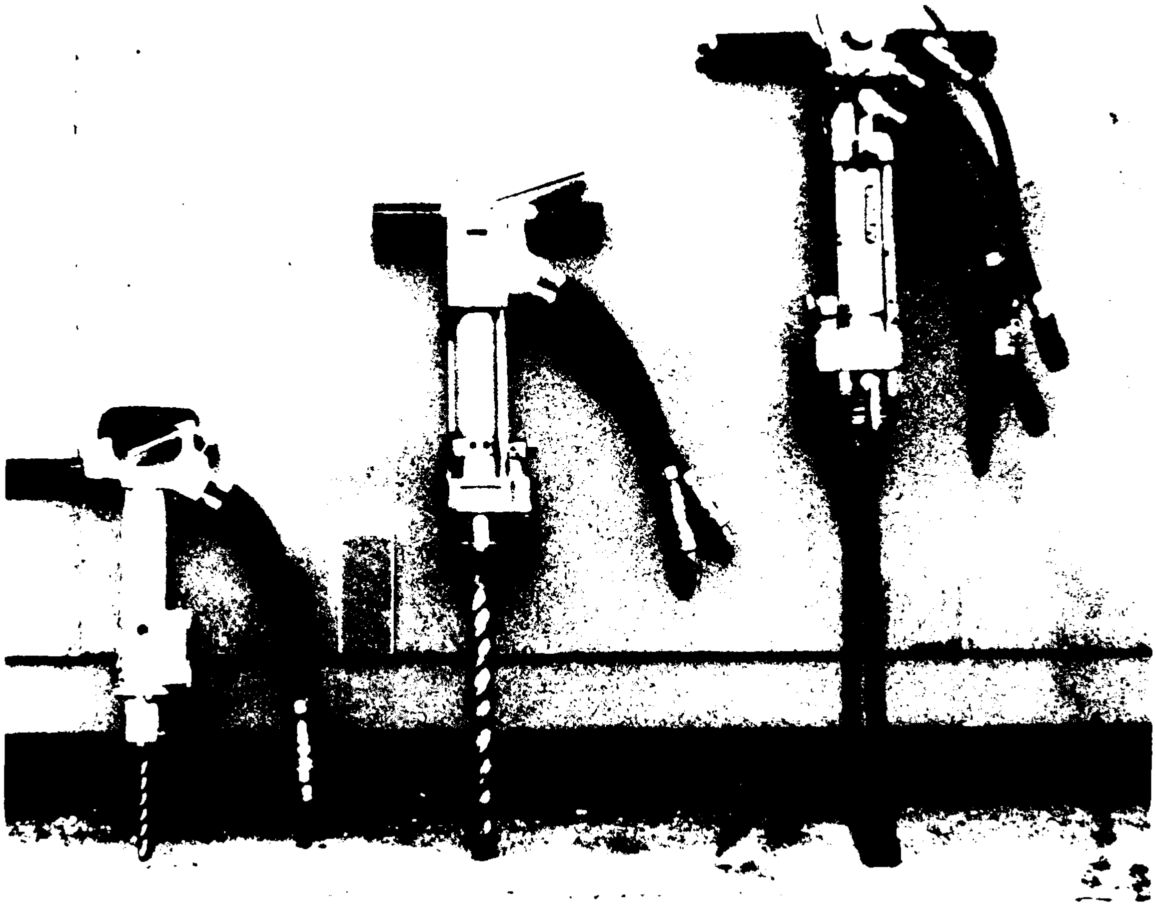

FIGURE 1 **THREE DRILLS EVALUATED**

- Unsafe operation caused by the absence of automatic shut off when the drill was released.

The light duty drill developed by NCEL in 1975 satisfactorily eliminated the problems associated with the pneumatic drills. While this new drill has been used successfully, the maximum drill bit diameter is 1-1/2 inches. Thus there was need for a hydraulic powered tool which could satisfy the size requirements for explosives and larger fasteners.

The larger hydraulic rock drill was developed by NCEL in 1977. This unit is capable of drilling holes of greater diameter and with a greater rate of penetration. It too has been used successfully by Navy divers. However, few units have been manufactured, and the demand has exceeded the supply.

Table 1 lists the characteristics of these two hydraulic rock drills.

Rock Drilling Theory

Most theories dealing with the mechanics of percussion drilling are based on the concept of specific energy. This concept states that for a given piece of drilling equipment and specific type of rock, the volume of material removed is proportional to the energy transmitted to the rock. This can be expressed by the equation.

$$V \approx \frac{E_D}{E_R} \tag{1}$$

where V = volume of rock removed ($in.^3$)

Usually, of more importance than the volume of rock removed, is the penetration rate of the drill into the rock. This can be determined from the equation.

Table 1. Characteristics of Hydraulic Rock Drills Developed by NCEL for Use by Divers

Characteristic	Hand-Held Hydraulic Rock Drill	Heavy Duty Hydraulic Rock Drill
Drill weight in air	68.1 lb.	102 lb.
Drill weight in seawater	49.6 lb.	84 lb.
Drilling rate	0.75 in. diameter hole at 3.25 in./min.	2.0 in. diameter hole at 3.44 in./min.
Hydraulic requirements	800 psi at 8 gpm	2,000 psi at 10 gpm
Drill capabilities	1/4 in. to 1-1/2 in. diameter	1-1/2 in. to 4 in. diameter

$$P_r = \frac{K \frac{dV}{dt}}{A} \qquad (2)$$

where P_r = penetration rate (in./min)

In Equation 1, E_D is the only term that is a function of time. Therefore,

$$P_r = \frac{K \frac{dE_D}{dt} e}{E_R A} \qquad (3)$$

The term dE_D/dt for percussion drilling is equal to the energy of each impact (E_I) times the impact frequency (f), and the area of the hole is a function of the diameter of the drill bit (D). Substituting into Equation 3 yields an equation for penetration rate in terms of the characteristics of the rock and the drill.

$$P_r = \frac{4Kf\, E_I\, e}{\pi\, E_R D^2} \qquad (4)$$

To maximize the drilling rate, an impactor should be selected that would maximize the product of the impact energy and impact frequency. In Reference 3 it is shown that, for pneumatic drills, the transmission efficiency (e) is a function of the bearing load since power can only be transmitted when the bit is in contact with the rock. This functional relationship was also reported for hydraulic rock drills in Reference 4. A maximum penetration rate is obtained when the thrust is equal to the minimum value required to return the bit to the rock between impacts. The penetration rate decreases then as the thrust continues to increase because the bit does not index properly, (see Reference 5).

The indexing angle (angle through which the bit rotates between impacts) also affects the drilling rate, according to Reference 6. Optimum indexing angles were found to be a function of applied energy, rock type, and drill bit type. These optimum angles ranged from 15 degrees for granite to 44 degrees for limestone. Although indexing angle does not appear in the penetration rate equation, its effect is accounted for in the energy transmission efficiency term (e).

Objectives

The primary purpose in selecting the three commercially manufactured rock drills for evaluation was to provide Navy divers with tools which could be easily procured and which had readily available replacement parts. These rock drills will supplement those developed by NCEL, and the performance of the Stanley products was therefore expected to be equal to or greater than that of the NCEL prototypes.

Based on drilling performance, reliability and maintainability, the underwater noise level, and overall hazard and safety aspects determined during the test program, each drill was evaluated for adequate safety and performance for Navy diver use.

The specific test objectives included:

1. Determination of all potential safety hazards.

2. Development of tool modifications and/or operating procedures to minimize the hazards.

3. Measurement of the relationship between hydraulic flow rate and port pressure, stall pressure, and impact frequency.

4. Determination of the optimum flow rate for achieving the greatest penetration (drilling) rate. (Measured on land.)

5. Determination of the optimum index angle for achieving the greatest penetration rate. (Measured on land.)

6. Determination of the optimum bearing load for achieving the greatest penetration rate. (Measured on land.)

7. Determination of the effect of underwater operation on the performance of the drill by repeating the objectives in item 6 in shallow water.

8. Determination of the effect of increased hydrostatic pressure on the performance of the drill by measuring in deep water the penetration rate for each drill bit size with flow rate, index angle and bearing load optimized according to the results of items 4, 5 and 7.

9. Determination of component reliability by dismantling and inspecting the drill following the tests.

10. Evaluation of safety, performance and acceptability by interviewing the divers following the tests.

11. Determination of the potential for hearing damage to divers operating the tools by measurement of the underwater noise produced by the rock drills.

TEST PROGRAM

Overview

The test objectives, as previously stated, required testing on land and in the water. A total of four different test sites were used.

The Hydraulic Laboratory was used for determining the general operating and physical characteristics of each drill when it was initially received by NCEL. These items included the running pressure, maximum torque, impact frequency, and the stall pressure. The second set of land-based tests involved actual drilling of holes. The optimum flow rate, index angle, and bearing load for maximizing the penetration rate were determined.

The Shallow Water Test Facility at NCEL, providing 12 feet of water depth, was the site of the first underwater tests. These included measurement of actual underwater drilling rates. The deep water operating tests were conducted in open water near Anacapa Island, off the coast of southern California. These tests, in 45- to 60-foot water depths, were used to determine the effects of hydrostatic pressure and other deep water phenomena on drill performance and to verify those measurements made during the shallow water tests.

The underwater noise measurements were made at the Naval Coastal Systems Center in Panama City, Florida. This facility also analyzed the data and reported on the results in References 7, 8 and 9.

Test Equipment

The first three test activities - laboratory, shallow water and deep water - utilized the following items provided by NCEL Code L43:

1. Stanley hydraulic hammer drill, model HD20 (1)

2. Stanley hydraulic hammer drill, model HD45 (1)

3. Stanley hydraulic sinker drill, model SK58 (1)

4. Hydraulic power source (1)

5. Hydraulic hose, 3/4 inch diameter (250 feet)

6. HD series drill bits: 1/2 inch, 3/4 inch, 1 inch, 1-1/4 inch, 1-1/2 inch (2 each)

7. SK58 series drill bits: 1-1/2 inch, 2 inch, 2-1/2 inch, 3 inch (2 each)

8. Pressure transducers (2)

9. Flow meter (1)

10. Oscillograph (1)

11. Strobe tachometer (1)

12. Torque meter (1)

13. Tape measure (1)

14. Stop watch (1)

15. Ten-pound weights (5)

The underwater noise level tests also used the three Stanley drills, items 1, 2 and 3. Additional equipment included:

16. MRI 319, Ser. No. 103 hydrophone (1)

17. Wideband amplifier (1)

18. Bell and Howell model 4020 magnetic tape recorder (1)

19. Bruel and Kjaer model 4134 microphone and amplifier (1)

20. MK 12 diving helmet (1)

21. Wet suit material, 1/4 inch thick

22. HD20 drill bit, 1/2 inch diameter (1)

23. HD45 drill bit, 1 inch diameter (1)

24. SK58 drill bit, 1 inch diameter (1)

Laboratory Test Procedures

Each of the three Stanley rock drills was tested according to the following procedures.

A pressure transducer was installed on the high pressure line of the drill. A second pressure transducer and a flow transducer were installed on the low pressure line. Each transducer was connected to an oscillograph where a permanent data record was produced. A needle valve was installed in the low pressure line to vary the back pressure. See Figure 2.

The drill was operated with a series of flow rates ranging from 4 to 9 gallons per minute. At each setting, the needle valve was slowly closed until the drill stalled. The oscillograph record provided blow (impact) frequency, running pressure at each port and stall pressure for each flow rate.

The strobe tachometer was used to measure the rotational rate of the drill. This was done for a series of different flow rates and valve settings, both of which affect the rotational rate.

The torque generated in the drill bit was measured by operating the tool with the bit inserted into a torque meter. This value was determined at a series of flow rates.

Land Test Procedures

Following the laboratory test measurements of tool characteristics, the actual drilling performance was determined. The rock used in these tests was granodiorite obtained from the Smit Quarry in Saugus, California. Some specimens contained veins of mica, and this heterogeneity of the material may have contributed to the variation in the measured penetration rates. For each test condition, a minimum of three holes was drilled to

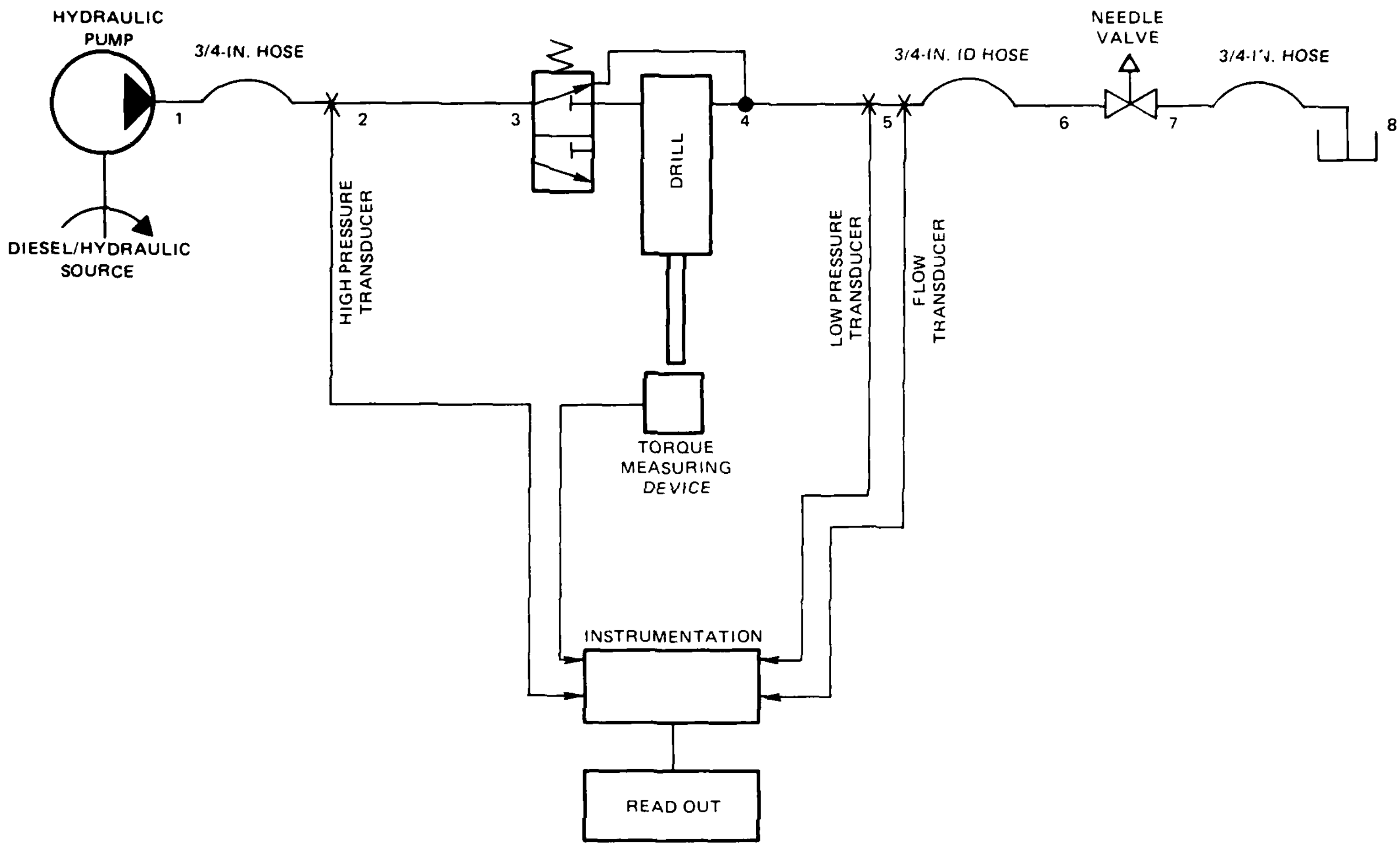

FIGURE 2 **SCHEMATIC OF THE LABORATORY TEST SETUP**

allow for the variation. In some cases, additional holes were drilled until the data were sufficiently clustered to define a single value.

Initially, for constant drill bit diameter, bearing load and rotational rate, the hydraulic flow rate was varied. For each flow rate, the depth of hole drilled during a fixed period of time was measured, and the penetration rate was determined. The optimum flow rate was determined to be that which resulted in the greatest penetration rate.

Keeping the drill bit diameter, flow rate, and bearing load constant, the rate of rotation and consequent index angle were varied. For each case, three or more holes were drilled for a fixed period of time to establish penetration rates. The optimum rotational rate was established as that resulting in the greatest rate of penetration.

This was followed by a test in which the bearing load was varied while the flow rate and rotational rate were held constant. The bearing load was established by applying lead weights. Holes were drilled, measured, and the penetration rates were determined for the different drill bit diameters. The optimum bearing load was that which resulted in the greatest penetration rate and also had acceptable handling characteristics.

The series of land tests described in the preceding paragraphs generated a set of conditions - hydraulic flow rate, rate of rotation, and bearing load - which resulted in the greatest rate of penetration into the granodiorite testing medium.

Shallow Water Test Procedures

The next series of tests was conducted in twelve feet of water in the Shallow Water Test Facility at NCEL, again using granodiorite as the drilled rock. This program involved procedures similar to those followed during the last set of land tests. With the flow rate and rotational rate held constant, the bearing load was varied for each drill bit size, (the optimum value established during the land tests was one of those tested). In each case the penetration rate was determined. The optimum in-water bearing load was chosen based on penetration rate and ease of handling by the divers.

Following these shallow water tests, the personnel who had used the tools were asked to report on the performance, handling, and safety of the equipment. A sample Critique Sheet is presented in Figure 3.

Deep Water Test Procedures

The tests in fifty feet of water near Anacapa Island were similar to those conducted in the shallow water facility. The flow rate and rotational rate were held constant, and for each drill bit size, bearing loads were tested. One was the previously determined optimum load. In each case the rate of penetration was determined.

Reliability and Maintainability Test Procedures

Following testing in the water, each drill was dismantled and checked for water leakage and damaged or worn parts.

Underwater Noise Measurement Procedures

The measurement of sound generated by each tool was accomplished by drilling underwater and recording the noise in three situations - at the diver's ear under a wet suit hood, without a wet suit hood, and inside a MK 12 diving helmet.

The underwater sound recording system consisted of a hydrophone, an

CRITIQUE SHEET
STANLEY HAND-HELD ROCK DRILLS

This questionnaire is to be completed by all personnel associated with the on-site testing of the Rock Drills.

This questionnaire should be completed by all test subjects and topside tenders immediately after each use of the Rock Drills. Any noteworthy comments by other personnel should be recorded in "other comments" section of this questionnaire.

1. Name (Last, first, middle) ____________ 2. Rate/Rank ____________

3. Duty address ____________

4. Stanley Hand-held Rock Drill Model tested ____________

5. Previous experience with Stanley Hand-held Rock Drills: YES NO

6. Previous experience with underwater tools? YES NO

7. If answer to #5 was YES, specify: ____________

8. Your part in test (i.e. operator, tender, etc.) ____________

9. Were any safety hazards noted or encountered? YES NO

10. If answer to #9 was YES, specify: ____________

11. Were any handling problems noted or encountered? YES NO

12. If answer to #11 was YES, specify: ____________

13. Do you have any recommendations for improvements? YES NO

14. If answer to #13 was YES, specify: ____________

15. Other comments: ____________

____________ Signature ____________ Date

FIGURE 3 CRITIQUE SHEET

amplifier and a tape recorder. The system was calibrated by impressing a known 1000 Hz signal on the hydrophone preamplifier and adjusting the output signal. Sound in air was measured using a microphone, amplifier and tape recorder, and this system was also calibrated using a known sound source.

The rock drill was operated by divers on concrete using various diameter drill bits. Measurements were made at the diver's ear with the hydrophone and with the hydrophone covered with a boot made of 1/4-inch wet suit material. The boot simulates the noise shielding afforded by a diver's wet suit hood. Measurements were also made with the hydrophone positioned 6 feet horizontally from the tool. The MK 12 helmet with the microphone was positioned next to the operator's head to simulate its location during normal operations.

One-third octave band levels for the selected tests were determined for the noise produced by the tool using a General Radio Model 1921 one-third octave band analyzer. The spectrum printouts of the individual tests were combined to give an average sound pressure level spectrum for each situation, SCUBA diver with and without wet suit hood protection, and MK 12 helmeted diver. These spectra were then summed to calculate the average overall sound pressure level. Corrections discussed in "Procedures for Noise Measurements of Diver Tools," an unpublished report by David B. Wyman of the Naval Coastal Systems Center, were then applied to the hydrophone data. The corrections are as follows:

Change reference level from 1 micropascal to 0.000204 dynes/cm^2	-26 dB
A-weighting and acoustics impedance mismatch between water and diver	-51 dB

The total correction equals -77 dB.

The microphone data was taken in air inside the MK 12 helmet with A-weighting applied. Therefore, the microphone data required no correction. Finally, the overall sound pressure levels were compared with the OSHA in-air standards to determine if hearing damage would occur and if any exposure time limits should be recommended.

STANLEY HYDRAULIC HAMMER DRILL, MODEL HD20

Technical Description

The Stanley hydraulic hammer drill model HD20, Figure 4, is a light duty hand tool. This tool is built for ease of handling. The model HD20 drills 1/2 inch to 1-1/2 inch diameter holes up to 18 inches deep. It uses standard carbide tipped fluted drills (Skil #736) and requires no fluid to clean the hole. The hammer drill hits an object at over 2000 blows per minute. A summary of the rock drill characteristics is listed in Table 2.

Table 2. Rock Drill Characteristics Model HD20

Characteristic	Description
Capacity	No. 736 Skil Carbide-Tip Bits
Weight	28 lbs.
Length	21 in.
Width	5 in.
Pressure	1500-2000 psi
Flow Range	7-9 gpm
Optimum Flow	8 gpm
Porting	3/8" SAE

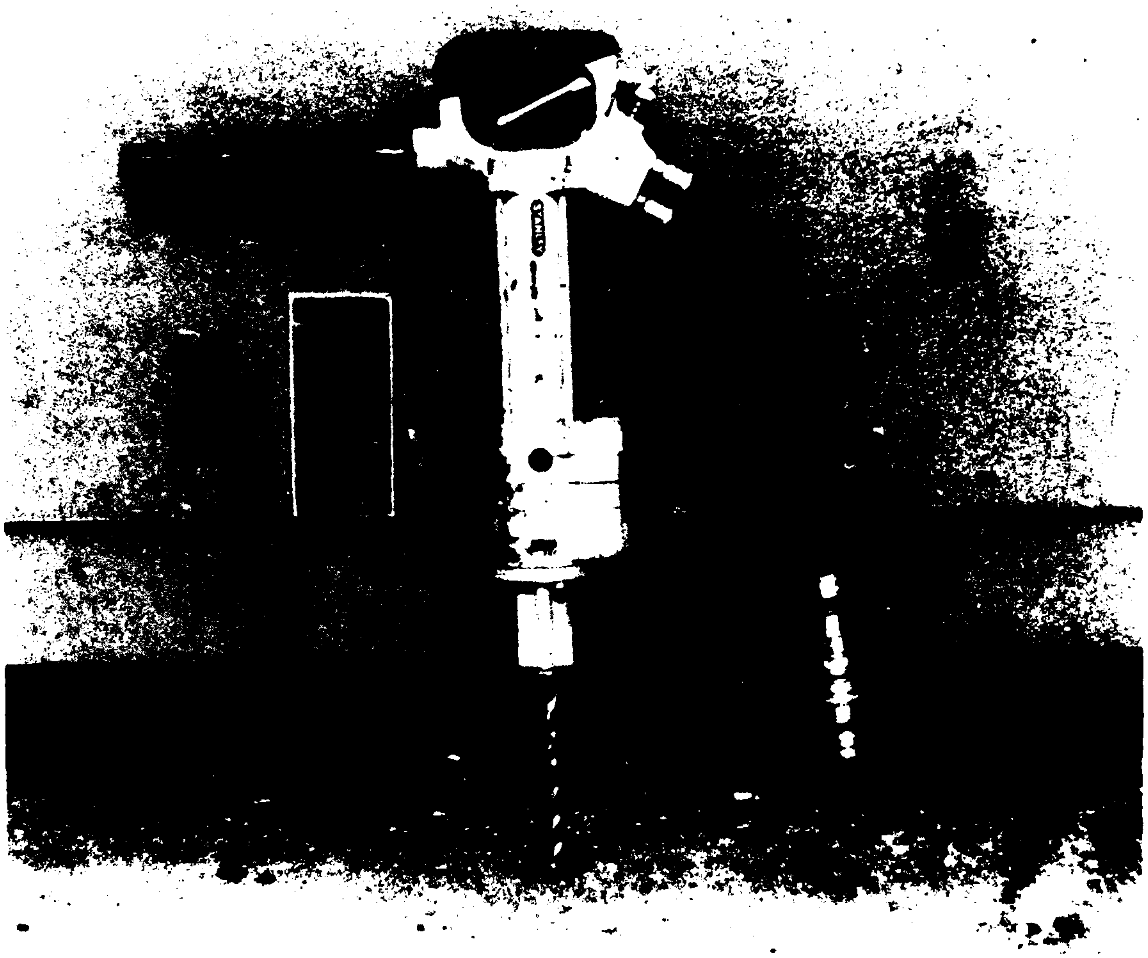

FIGURE 4 **MODEL HD 20 DRILL**

Hose Whips	Yes
Connect Size and Type	3/8" male pipe hose end
Hyrevz Motor	Integral
Rotation Speed	0-300 rpm

Laboratory and Land Test Results

The operating characteristics of the drill measured during the laboratory testing are listed in Table 3.

The land tests for determining the operating characteristics which result in the greatest penetration rates were conducted using twenty foot hydraulic hoses between the power source and the drill. This neglected the additional back pressure which would result from the 250 foot hoses used in underwater service.

Six flow rates were used in the tests to determine the optimum value for maximizing the drilling rate. Those tested were 4,5,6,7,8 and 9 gallons per minute. The drill bit diameter was held constant at 1/2 inch. The results of the test are shown in Figure 5. Based on these data, the 8 gallon per minute value was chosen as the optimum setting.

Rotational rate is controlled by the rotor motor valve, and the valve setting was chosen as a suitable description of the rotational rate. This is a convenient measure for the diver, because without the use of any

Table 3. Operating Characteristics of Model HD20 as Measured during Laboratory Tests

Flow Rate (GPM)	Running Pressure (PSI)		Stall Pressure (PSI)		Number of Valve Turns	Impact Frequency (Hz)
	High	Low	High	Low		
3.10	575	125	-	275	1	10.25
5.17	950	150	2200	550	1	16.00
6.55	1275	150	2400	550	1	19.00
7.81	1650	175	2400	>450	1	21.50
8.50	1950	175	2400	500	1	22.00
7.93	2200	175	2400	525	1	19.25
8.74	-	-	-	-	5	0.00
7.78	1875	175	2400	450	2-1/2	14.00
			RPM			
7.47	1100	175	260		1	18.50
7.47	1050	175	240		1-1/2	16.00
7.47	1050	175	225		2	12.50
7.82	2275	200	250		1	15.25
8.40	2250	200	250		1-1/2	15.00
8.75	2250	200	250		2	15.25
8.28	1950	200	250		2	13.75
8.10	2050	200	240		1-1/2	14.25
7.70	2175	200	250		1	15.50

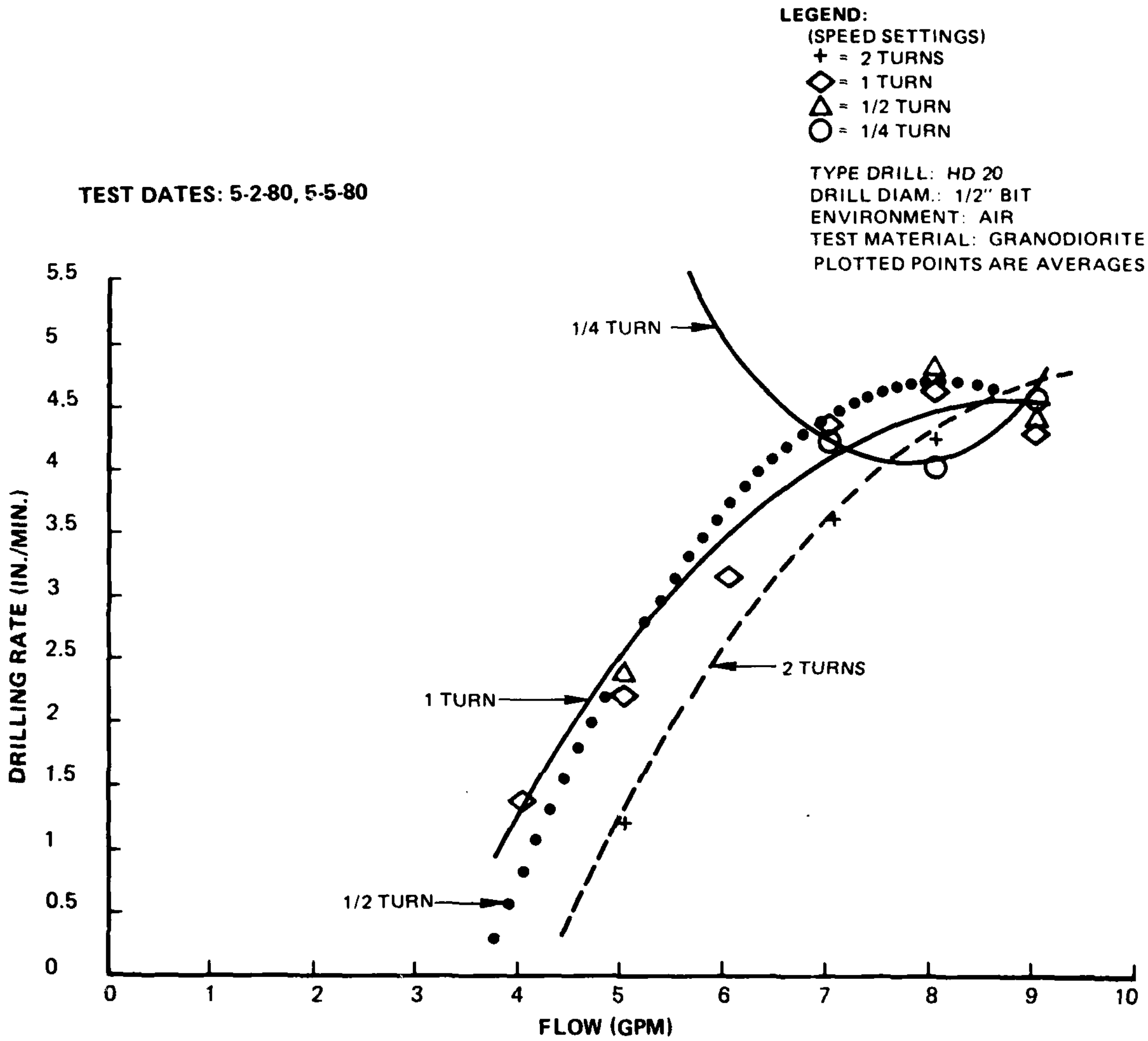

FIGURE 5 **DRILLING RATE VERSUS FLOW FOR THE HD 20 LAND TEST FOR DETERMINING THE OPTIMUM FLOW RATE**

measuring tools he is able to set the rotational rate. With the number of valve turns from the fully open position as the measure, a plot of rotational rate versus penetration rate for four flow rates and a 1/2 inch diameter drill bit is shown in Figure 6. These data established 1/2 turn as the setting for the optimum rotational rate resulting in the greatest drilling rate.

A belt with variable lead weights slung over the drill handle was used to vary the bearing load. The weights tested ranged from zero to 78 pounds applied to the rock drill operating with a flow rate of 8 gpm and the valve set at 1/2 turn. The results are illustrated in Figure 7. Although increased weight increased the drilling rate, the tool became difficult to handle with high bearing loads, and the drilling rate increased at a slower rate. These considerations resulted in 48 pounds being selected as the optimum bearing load.

With the rotational rate at its optimum value and no added bearing load, four drill bit sizes - 3/4 inch, 1 inch, 1-1/4 inches and 1-1/2 inches - were tested for penetration rate at four flow rates. The results are plotted in Figure 8.

The same tool settings and drill bits were used with 250 foot hydraulic hoses to measure the effects of the added back pressure. The results, shown in Figure 9, indicated that the use of longer hoses, typical in diving operations, would cause a reduction in the drilling rate.

Shallow and Deep Water Test Results

During the shallow water tests, the bearing load was again varied, and the drilling rate was measured to determine any change in the optimum weight resulting from underwater operation. The 48 pound load selected as optimum during the land tests, no weight and a weight of 72 pounds were applied. The penetration rate was greatly reduced with no weight, and the drill was difficult to handle with the higher weight applied, so the optimum underwater bearing load was determined to be 48 pounds, although it did not result in the greatest drilling rate, as shown in Figure 10.

The effect of bearing load on drilling rate was also measured in the deep water tests near Anacapa Island. With flow and rotational rates set at the previously established optimum values, penetration rates were measured with a 48 pound bearing load and with no added weight. The results for 1/2 inch, 1 inch and 1-1/2 inch diameter drill bits are plotted in Figure 11.

Following the underwater drilling tests, the divers were asked to evaluate the use of the tool. It was judged easy to handle and control. Mounting the trigger on the long handle was proposed as a way to make the drill easier to control. There were frequent incidents of the trigger locking device failing to disengage, requiring the diver to do it manually, and correction of this problem was recommended.

Reliability and Maintainability Test Results

Water was found in the gear casing following the deep water tests. This could result in rusting of the gears, so cleaning after each use was recommended. Pitting of the piston was also discovered, and may have been the result of salt water in the casing.

Underwater Noise Measurement Results

The tests which were analyzed are listed in Table 4. The data are presented in Figures 12 and 13.

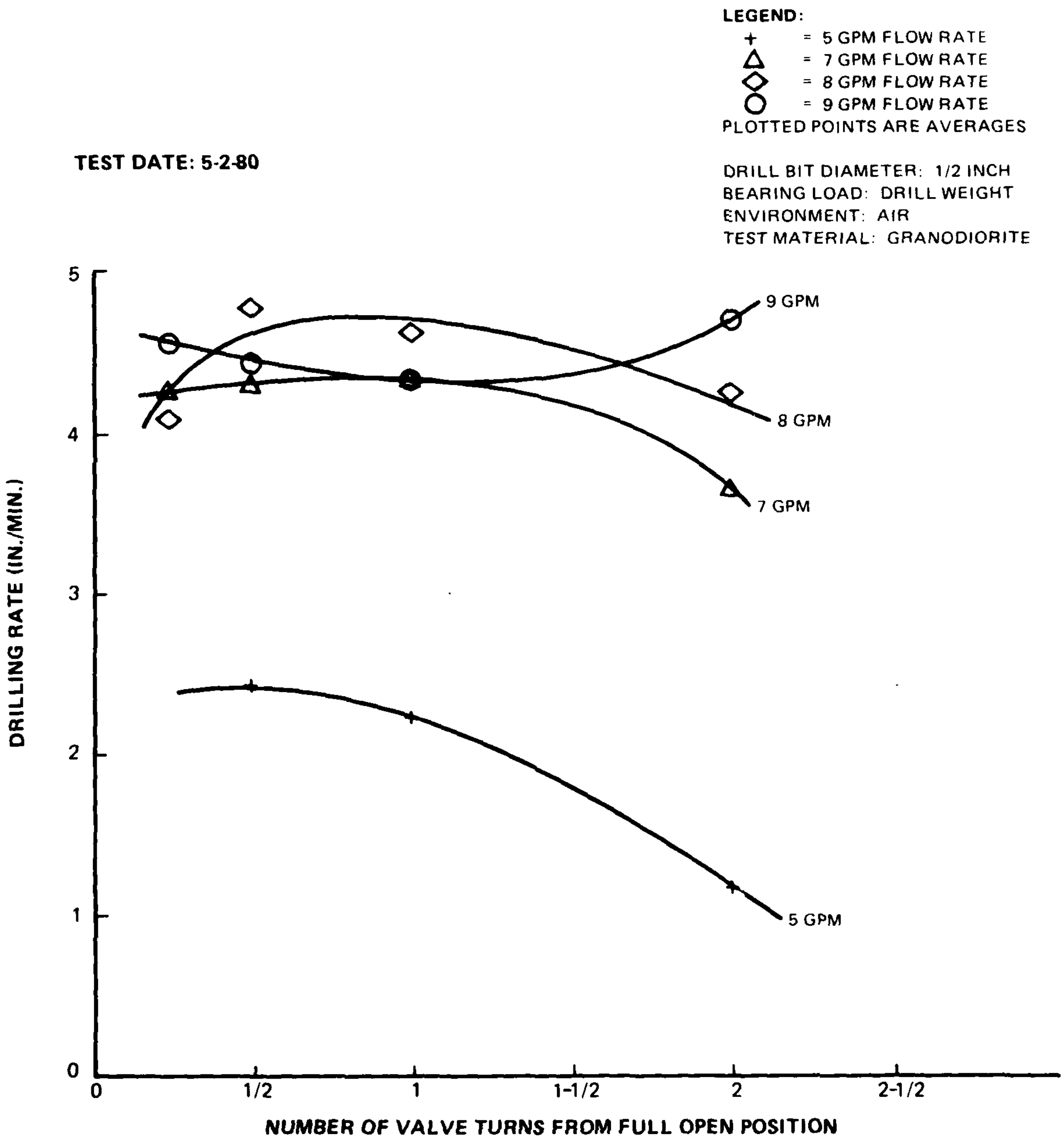

FIGURE 6 –DRILLING RATE VERSUS VALVE SETTING (WHICH DEFINES ROTATIONAL SPEED) FOR THE HD 20 LAND TEST FOR DETERMINING THE OPTIMUM ROTATIONAL RATE

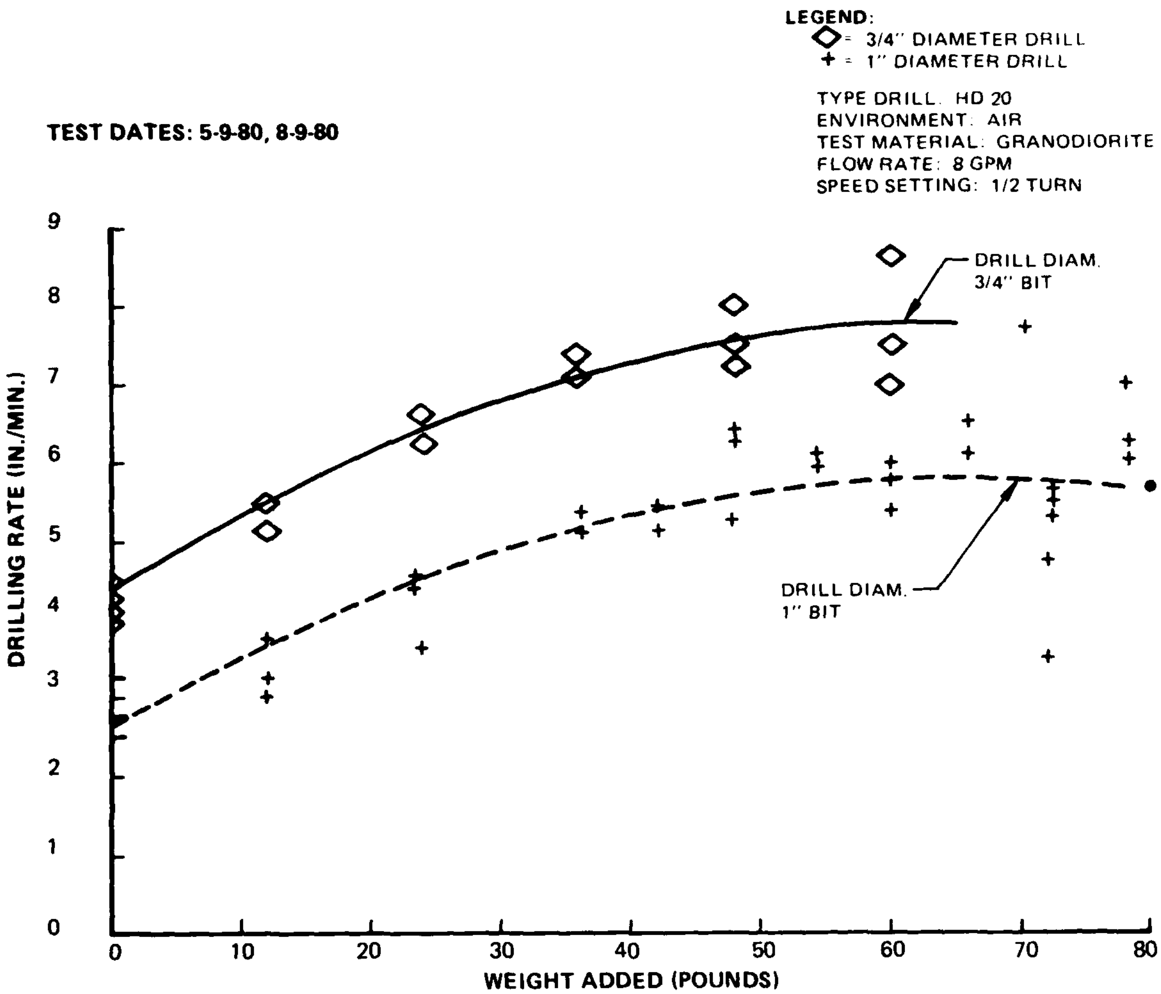

FIGURE 7 DRILLING RATE VERSUS WEIGHT ADDED FOR THE HD 20 LAND TEST FOR DETERMINING THE OPTIMUM BEARING LOAD

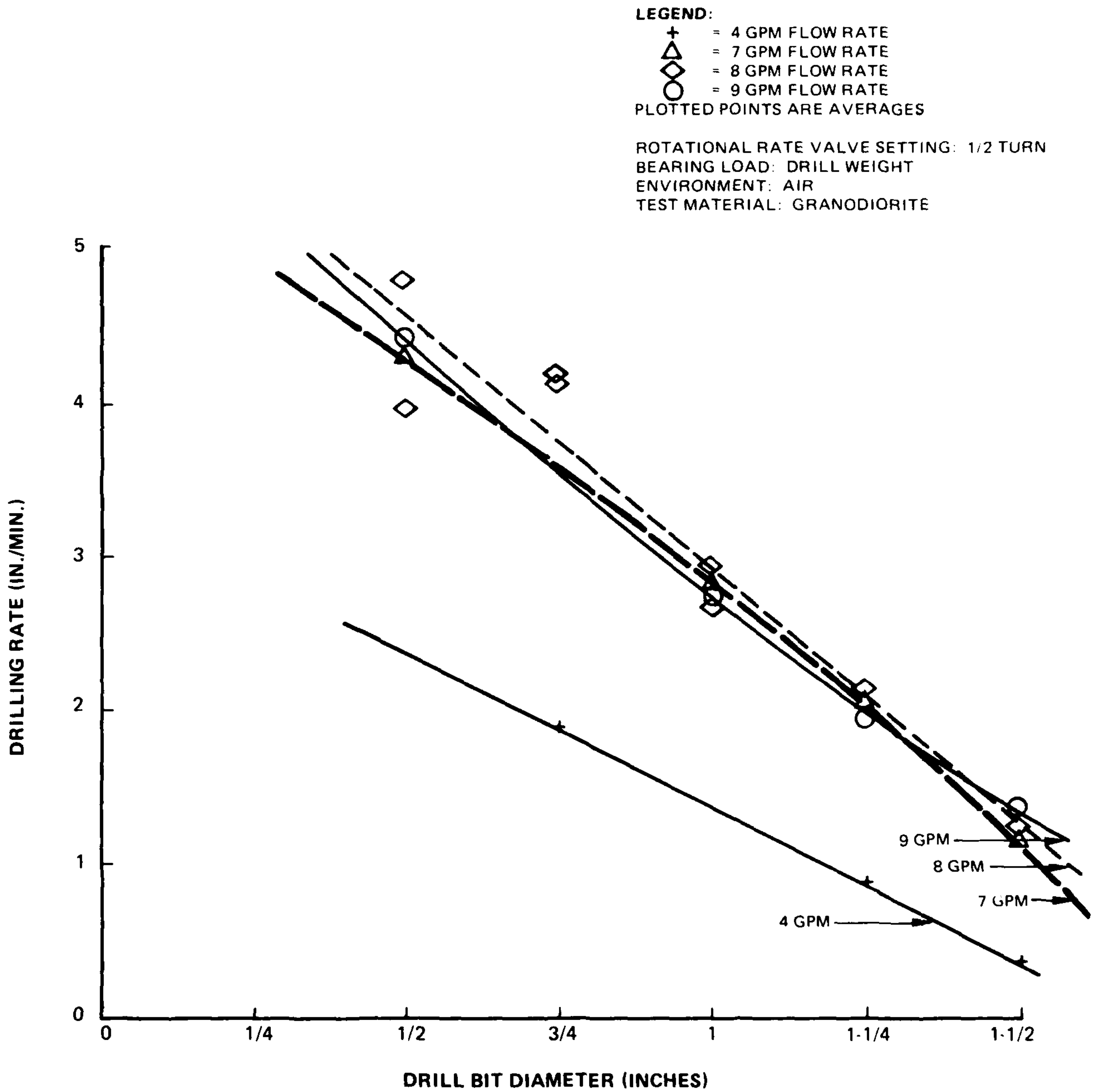

FIGURE 8 DRILLING RATE VERSUS DRILL BIT DIAMETER FOR THE HD 20 LAND TEST

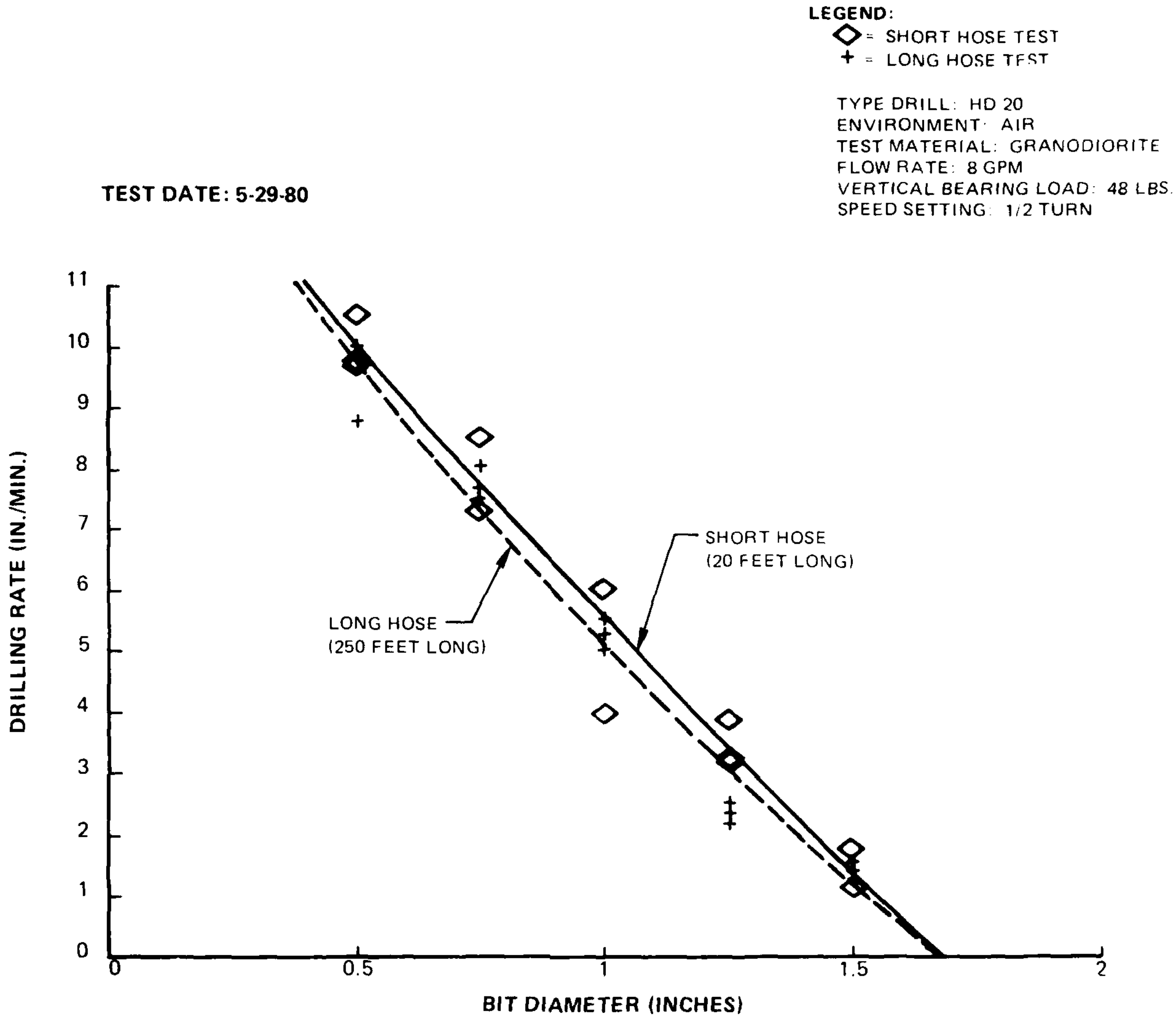

FIGURE 9 —**DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 20 LAND TEST FOR DETERMINING THE DRILLING RATES AND THE EFFECT OF BACK PRESSURE RESULTING FROM LONGER HOSES**

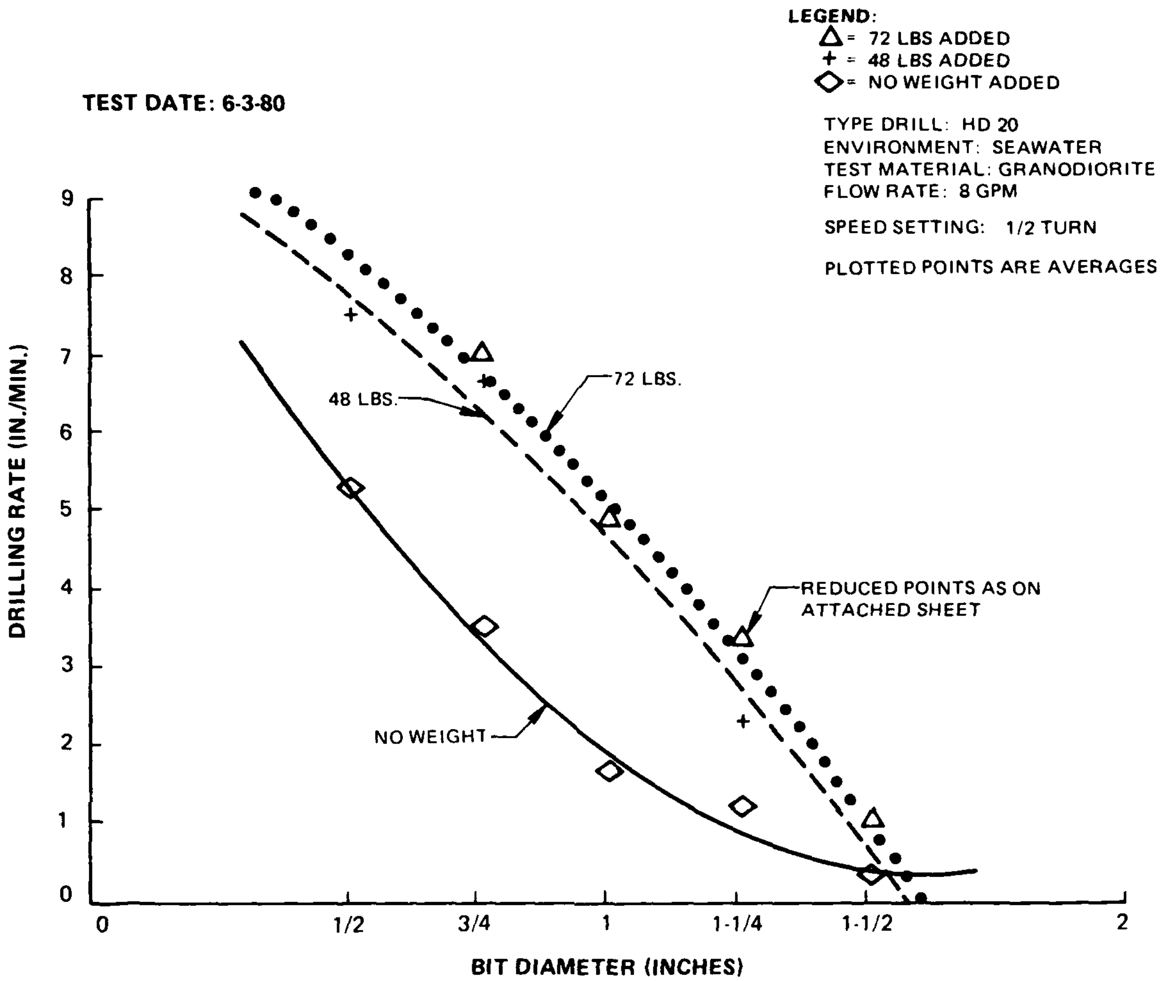

FIGURE 10 —DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 20 TANK TEST FOR DETERMINING THE OPTIMUM BEARING LOAD IN SHALLOW WATER

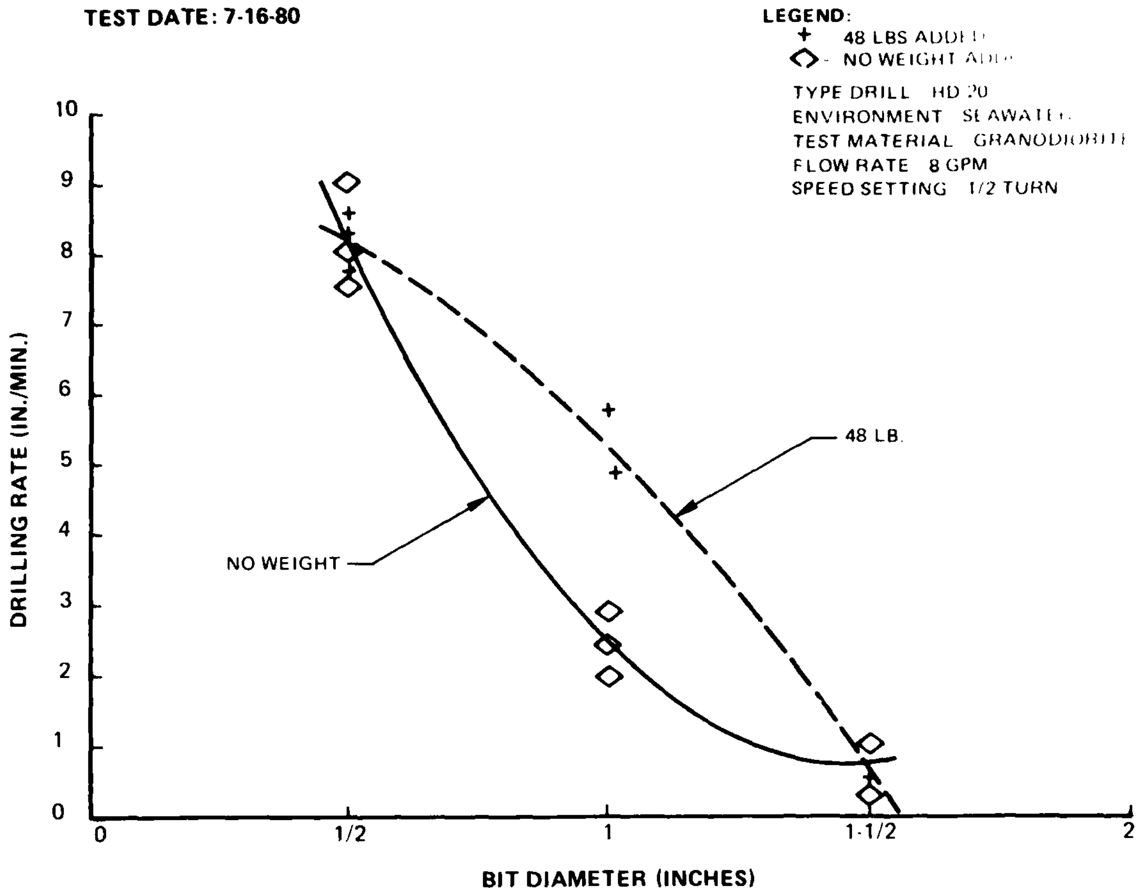

FIGURE 11 –DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 20 DEEP WATER TEST FOR DETERMINING THE EFFECT OF BEARING LOAD IN DEEP WATER

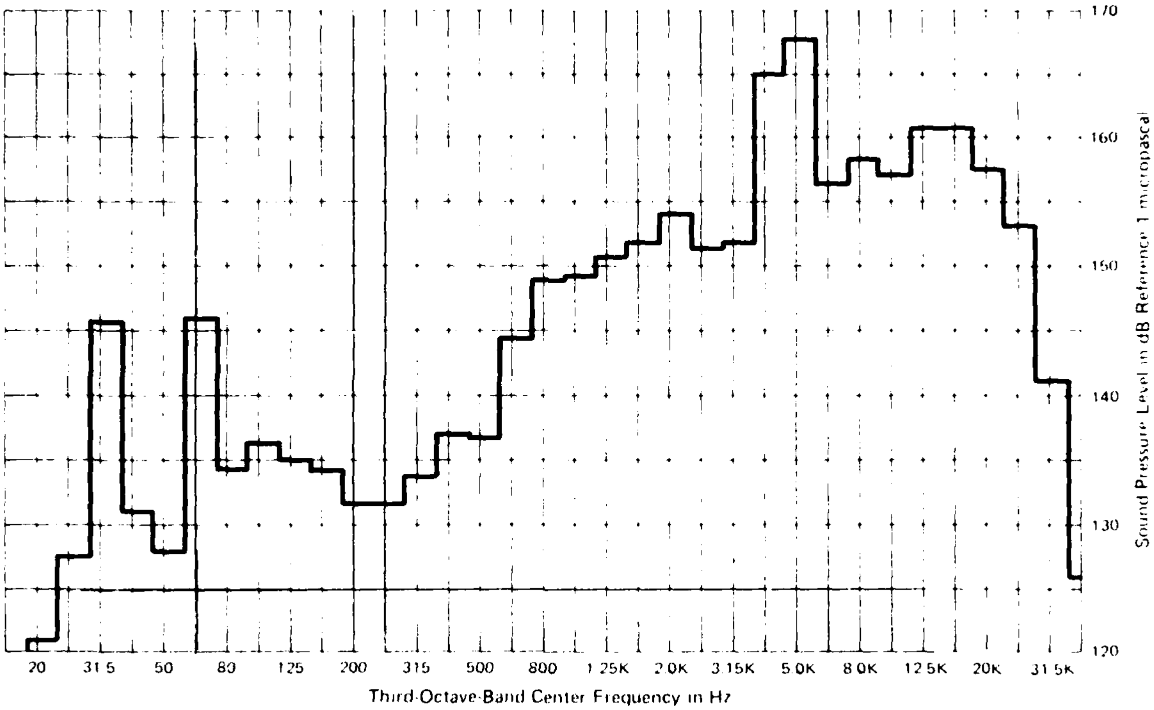

FIGURE 12 **AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER-OPERATED STANLEY ROCK DRILL, HD 20, HYDROPHONE 6 FEET FROM TOOL**

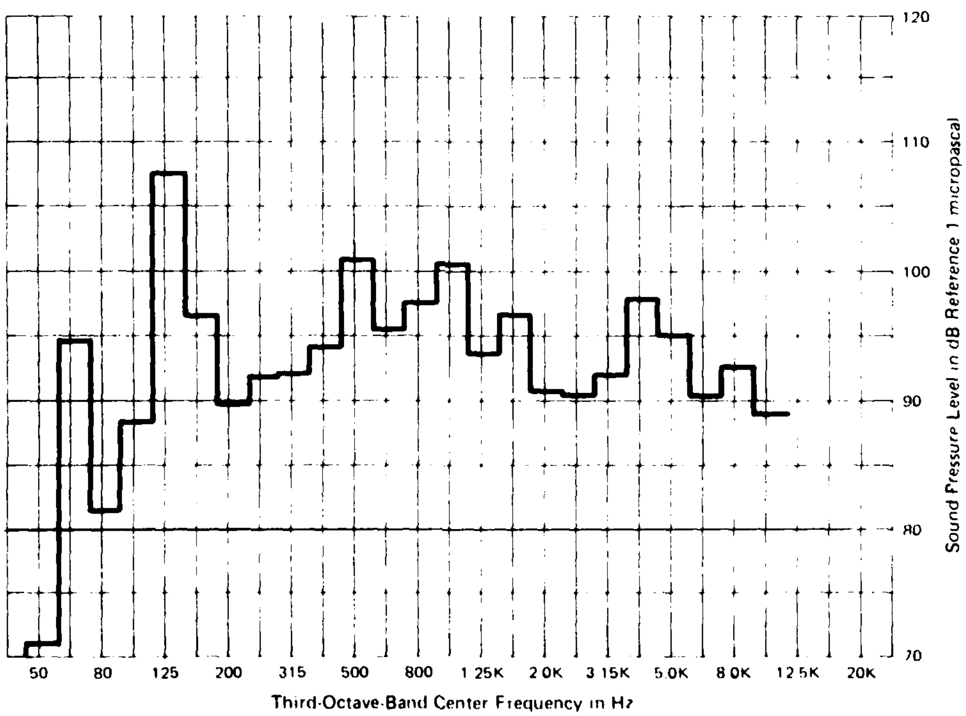

FIGURE 13 **AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER IN A MK 12 HELMET OPERATING A ROCK DRILL, HD 20**

Table 4. Noise Measurement Tests of Stanley Rock Drill, HD20

Drill Bit Diameter Inches	Hydrophone Location	Hydrophone Overall Sound Pressure Level Ref: 1 Micropascal	Microphone in MK 12 Helmet Location	Microphone Overall Sound Pressure Level Ref: 0.000204 dynes/cm^2 (A-weighted)
1/2	at diver's ear,	175		
1/2	6 feet from tool	161	4 feet from tool	85
1/2	at diver's ear, wet suit protected	163		

STANLEY HYDRAULIC HAMMER DRILL, MODEL HD45

Technical Description

The Stanley hydraulic hammer drill model HD45, Figure 14, is a heavy duty tool which may be used for drilling test holes, for setting anchor bolts, and similar underwater purposes. It drills 1/2 inch to 1-1/2 inch diameter holes up to 30 inches deep. The model HD45 uses standard carbide tipped fluted drills (Skil #736) and requires no fluid to clean the hole. The model HD45 has an additional feature of adjustable bit rotation (forward and reverse) which permits a choice of blows per minute/revolutions per minute ratios for easy starting of core drills and for maximum penetration. The model HD45 hammer drill delivers 2200 blows per minute. A summary of the rock drill characteristics is listed in Table 5.

Table 5. Rock Drill Characteristics Model HD45

Characteristic	Description
Capacity	No. 736 Skil Carbide-Tip Bits
Weight	45 lbs.
Length	22.5 in.
Width	14 in.
Pressure	1500-2000 psi
Flow Range	7-9 gpm
Optimum Flow	8 gpm
Porting	1/2" SAE
Hose Whips	Yes
Connect Size and Type	1/2" male pipe hose end
Hyrevz Motor	Integral
Rotation Speed	0-300 rpm

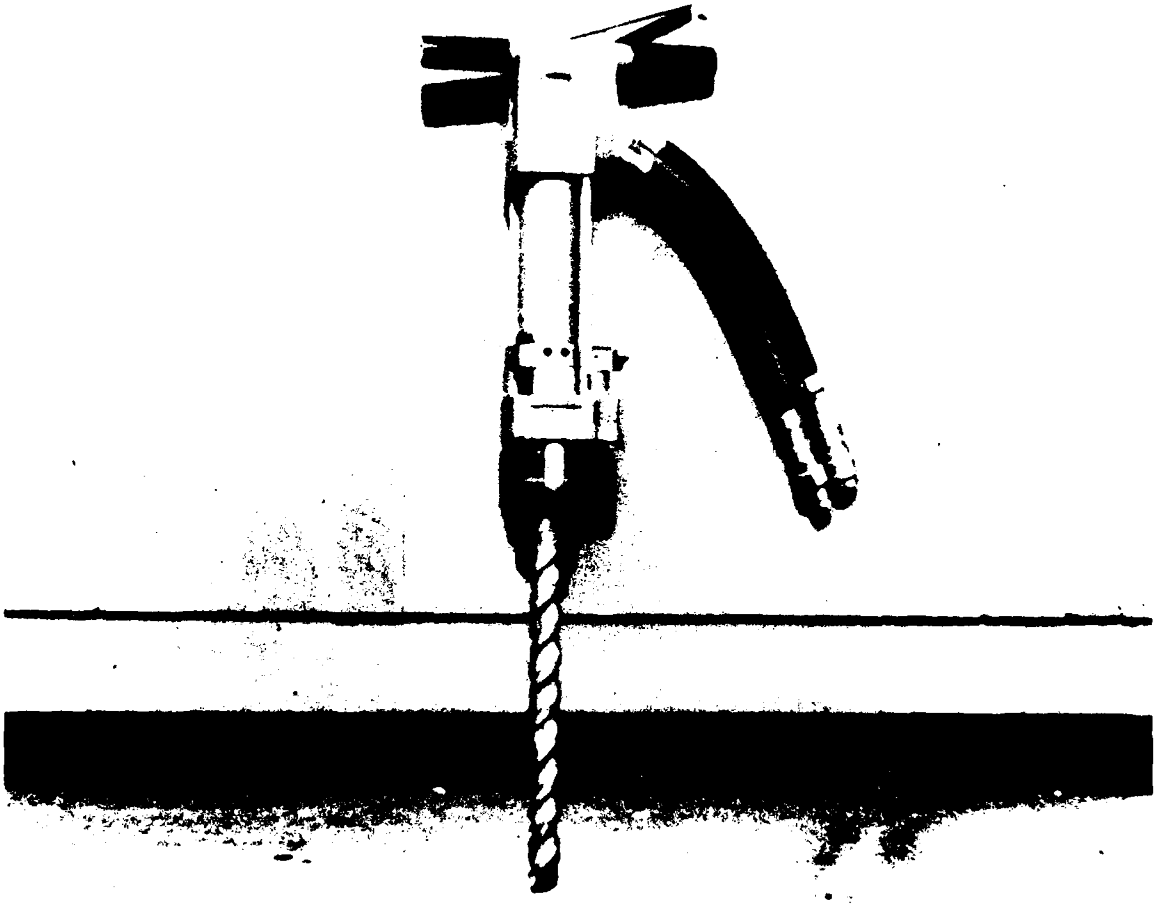

FIGURE 14 **MODEL HD 45 DRILL**

Laboratory and Land Test Results

The operating characteristics of the drill measured during the laboratory testing are listed in Table 6. The maximum torque developed, occurring at flow rates of 8 and 9 gallons per minute, was 15 foot-pounds. These tests utilized 20 foot hydraulic hoses, while all the tests following, on land and in water, used 250 foot hydraulic hoses to avoid the errors in drilling rate shown in Figure 9.

The flow rates tested to determine that which resulted in the maximum drilling rate were 4,6,7,8 and 9 gallons per minute. As shown in Figure 15, the penetration rate steadily increased with increasing flow rate. The optimum flow rate was chosen as 9 gallons per minute, based on the manufacturer's suggested maximum setting, rather than an absolute maximum drilling rate. With no additional bearing load, the resulting average penetration rate was 5-1/2 inches per minute with a 1 inch bit diameter.

The bearing load was increased at a constant flow rate of 9 gpm to determine the optimum value, and it was found that the drilling rate consistently increased with weight. The tool became difficult to handle with higher loads, so 54 pounds was selected as the optimum value, corresponding to a drilling rate of 9.7 inches per minute with a 1 inch drill bit. The results for the range of weights are plotted in Figure 16.

Table 6. Operating Characteristics of Model HD45 as Measured during Laboratory Tests

Flow Rate (GPM)	Running Pressure (PSI) High	Running Pressure (PSI) Low	Stall Pressure (PSI) High	Stall Pressure (PSI) Low	Impact Frequency (Hz)
3.68	575	75	950	200	17.0
5.06	800	75	-	-	18.2
6.32	1025	100	1600	450	22.5
7.59	1350	125	2125	450	22.5
8.27	1525	150	2175	500	23.0
9.65	1900	175	2375	575	24.0

Flow Rate (GPM)	Running Pressure (PSI) High	Running Pressure (PSI) Low	RPM	Impact Frequency (Hz)
3.62	600	100	10	18.9
6.34	1075	110	260	20.5
7.13	1290	125	327	21.0
8.27	1590	175	395	22.0
9.62	1900	200	465	27.0

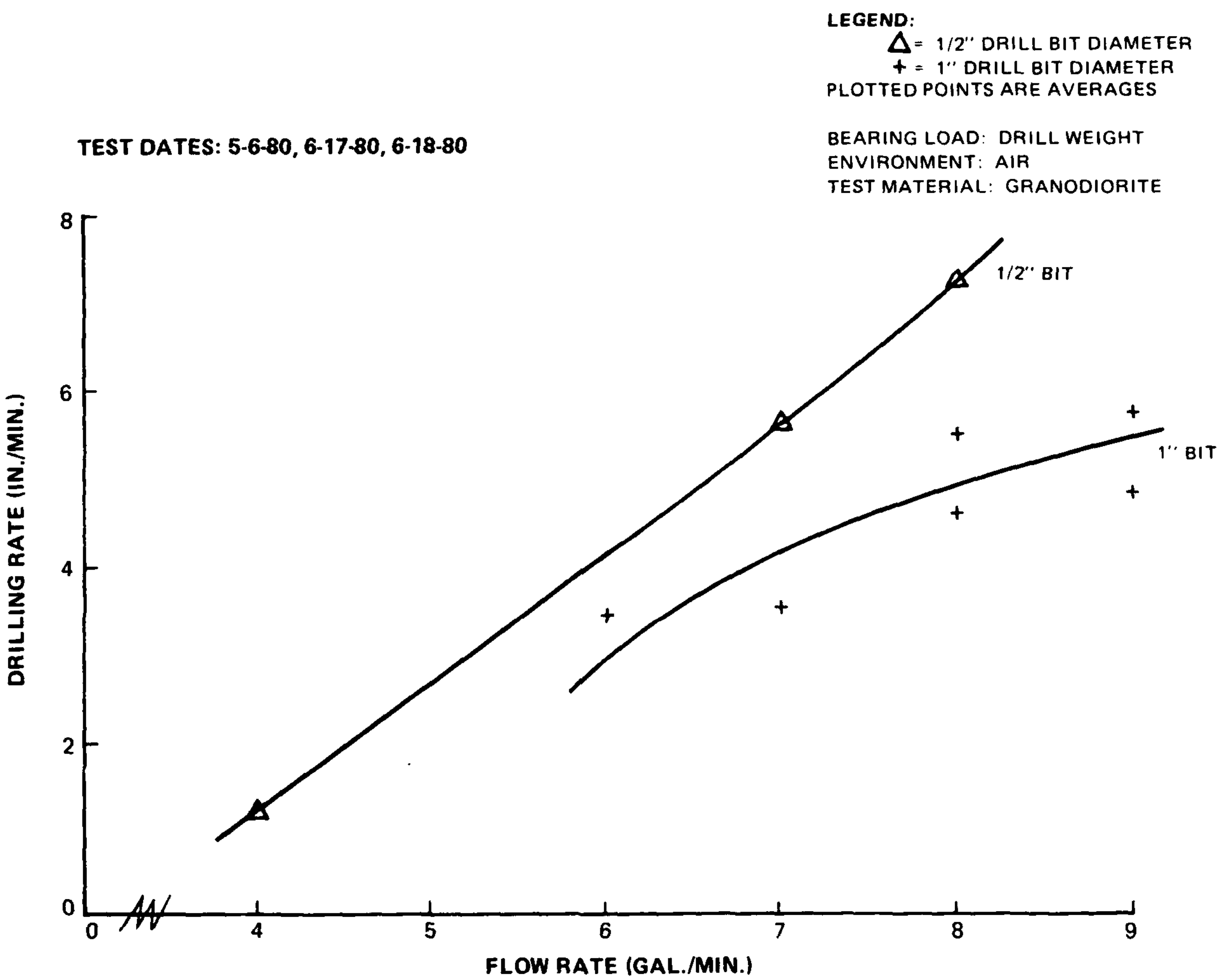

FIGURE 15 **DRILLING RATE VERSUS FLOW RATE FOR THE HD 45 LAND TEST FOR DETERMINING THE OPTIMUM FLOW RATE**

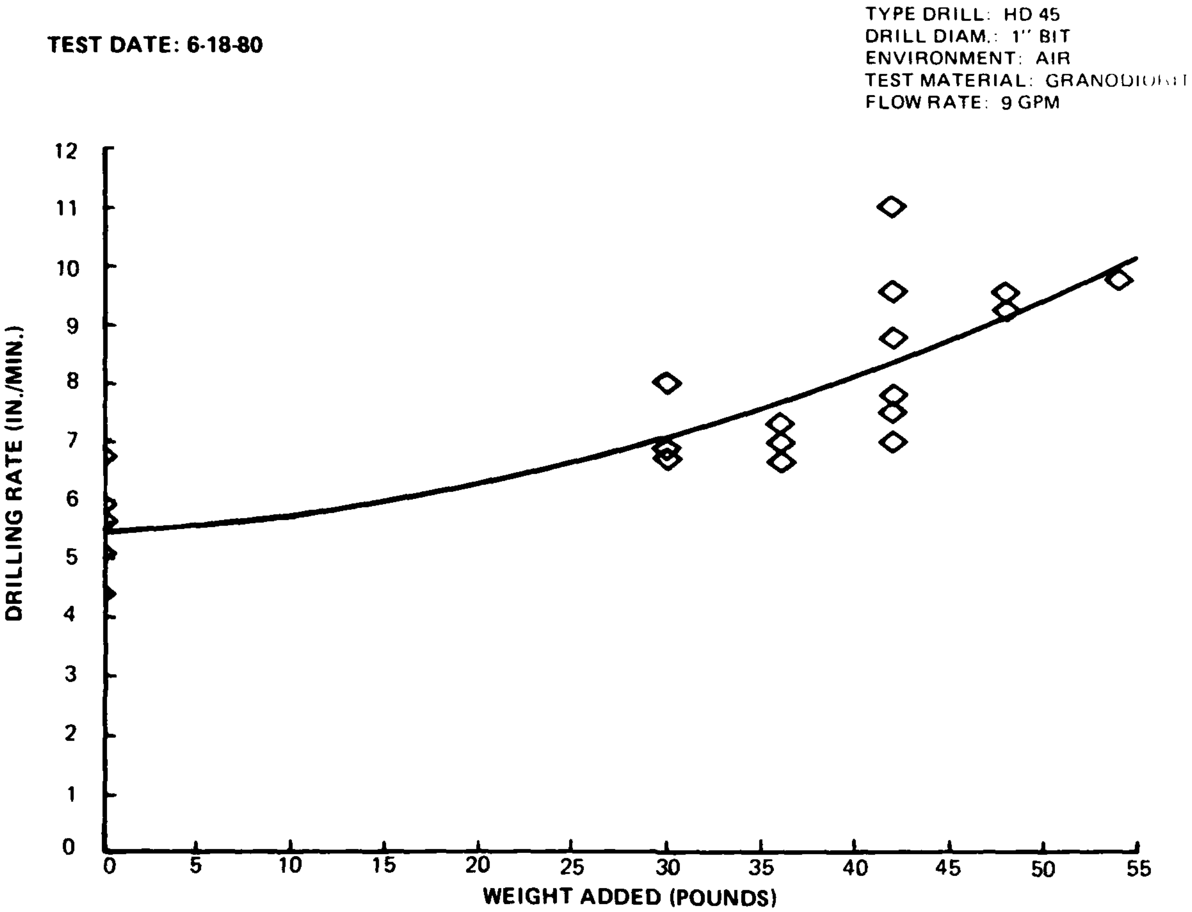

FIGURE 16 **DRILLING RATE VERSUS WEIGHT ADDED FOR THE HD 45 LAND TEST FOR DETERMINING THE OPTIMUM BEARING LOAD ON LAND**

The selected 54 pound optimum load and no added weight were used with a series of drill bit diameters and one flow rate to determine the drilling rate corresponding to each. The results are shown in Figure 17.

Shallow and Deep Water Test Results

Drilling in shallow water was performed with no added weight and with bearing loads of 30 and 54 pounds, all at a flow rate of 9 gpm with 5 different drill bit diameters. The drilling rates were less than on land and are shown in Figure 18. Although the 54 pounds resulted in the greatest drilling rate, it also created handling problems. The 30 pound bearing load was therefore chosen as the optimum value.

The bearing loads used in the deep water tests were zero and thirty pounds. Holes were drilled using 1/2 inch, 1 inch and 1-1/2 inch diameter drill bits with the flow rate set at 9 gpm. The results, shown in Figure 19, indicated that the drilling rates were significantly greater than those in shallow water.

The divers' evaluations of the tool were mostly favorable. It was reported that the drill was difficult to control when starting a hole, and it was suggested that a better way be developed for applying the bearing load. During the drilling, the 1/2 inch diameter bit often jammed in the hole, requiring the use of a wrench to free it.

Reliability and Maintainability Test Results

The dismantling of the rock drill following the underwater tests revealed some rusting. It was also discovered that the motor mounting bolts required a specific torque during reassembly, a condition not specified by the manufacturer.

Table 7. Noise Measurement Tests of Stanley Rock Drill, HD45

Drill Bit Diameter Inches	Hydrophone Location	Hydrophone Overall Sound Pressure Level Ref: 1 Micropascal	Microphone in MK 12 Helmet Location	Microphone Overall Sound Pressure Level Ref: 0.000204 dynes/cm^2 (A-weighted)
1	at diver's ear, wet suit protected	162		
1	6 feet from tool	171		
1	at diver's ear	174	4 feet from tool	84

TEST DATE: 6-19-80

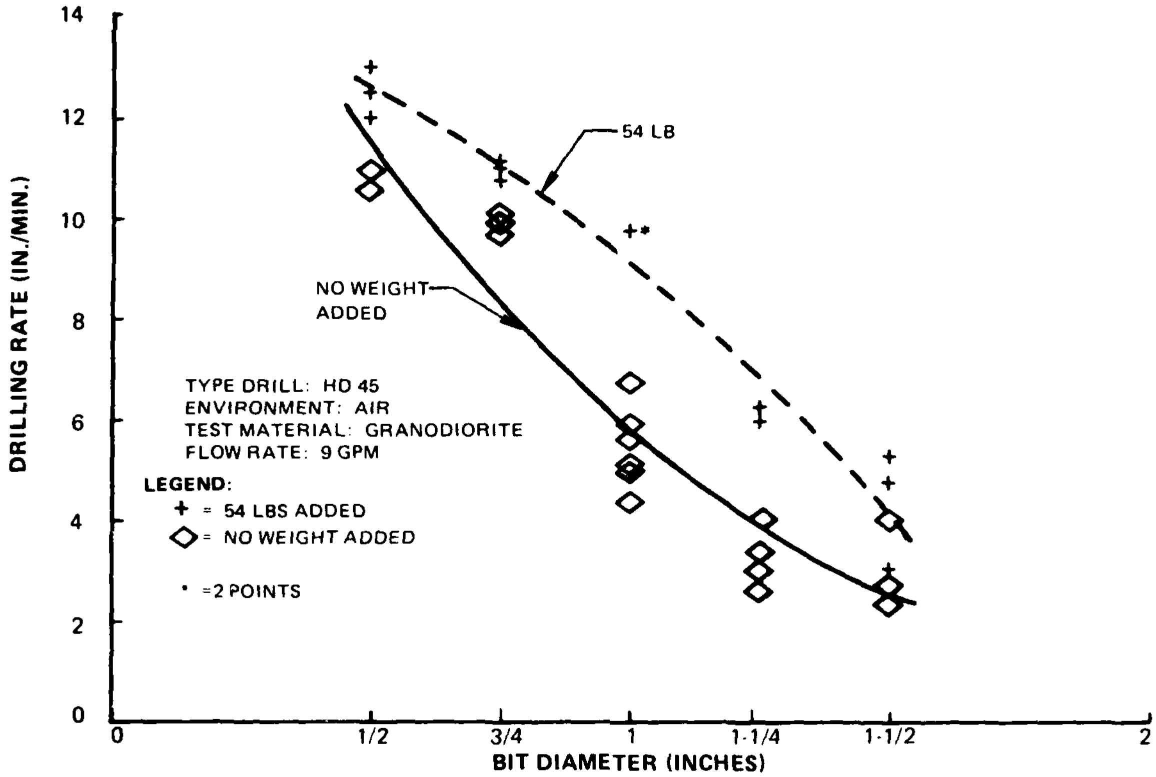

FIGURE 17 **DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 45 LAND TEST FOR DETERMINING THE EFFECT OF BEARING LOAD AND BIT DIAMETER ON DRILLING RATE ON LAND**

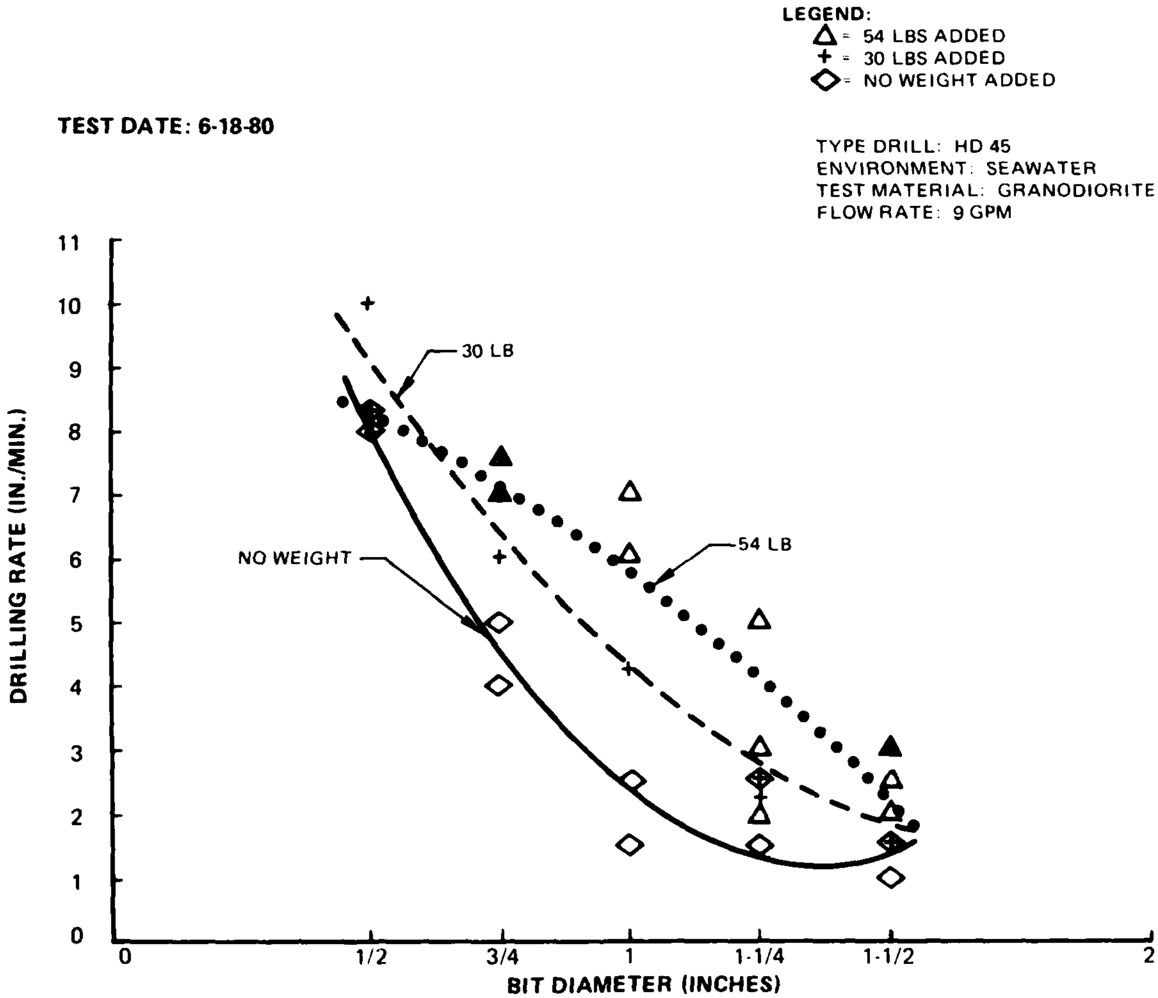

FIGURE 18 DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 45 TANK TEST FOR DETERMINING THE EFFECTS OF BEARING LOAD AND BIT DIAMETER ON DRILLING RATE IN SHALLOW WATER

TEST DATE: 7-16-80

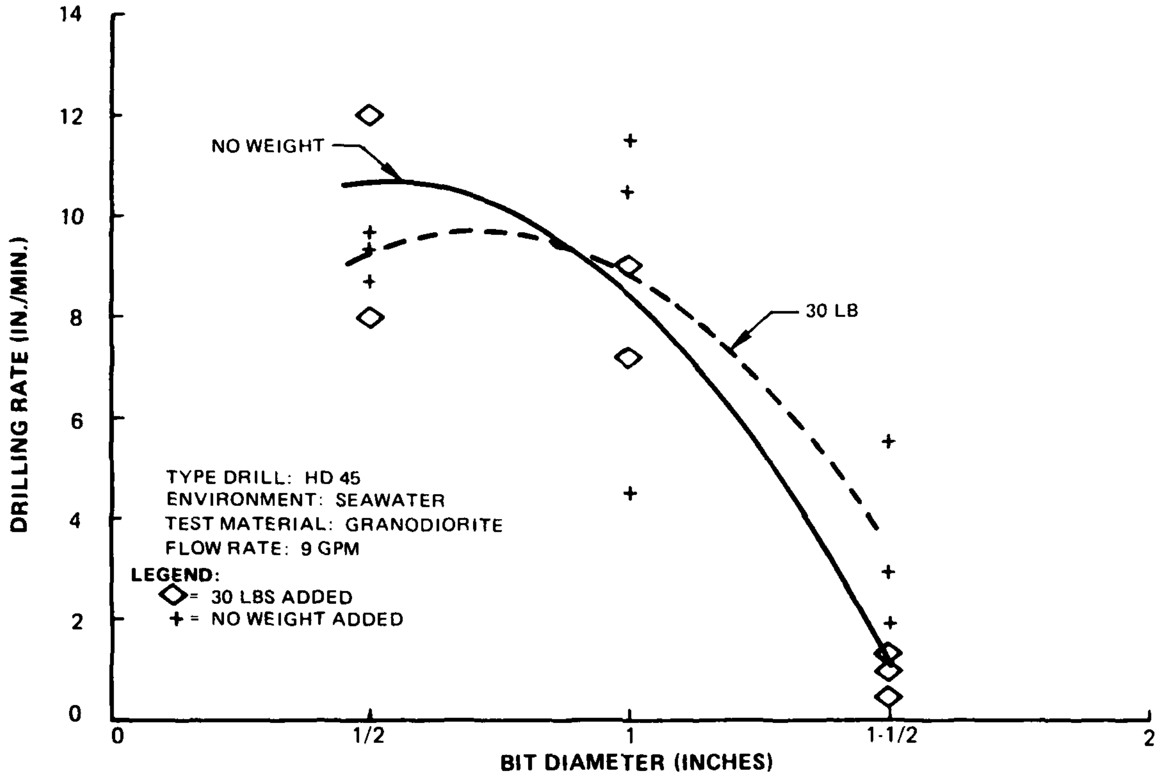

FIGURE 19 DRILLING RATE VERSUS BIT DIAMETER FOR THE HD 45 DEEP WATER TEST FOR DETERMINING THE EFFECTS OF BEARING LOAD AND BIT DIAMETER ON DRILLING RATE IN DEEP WATER

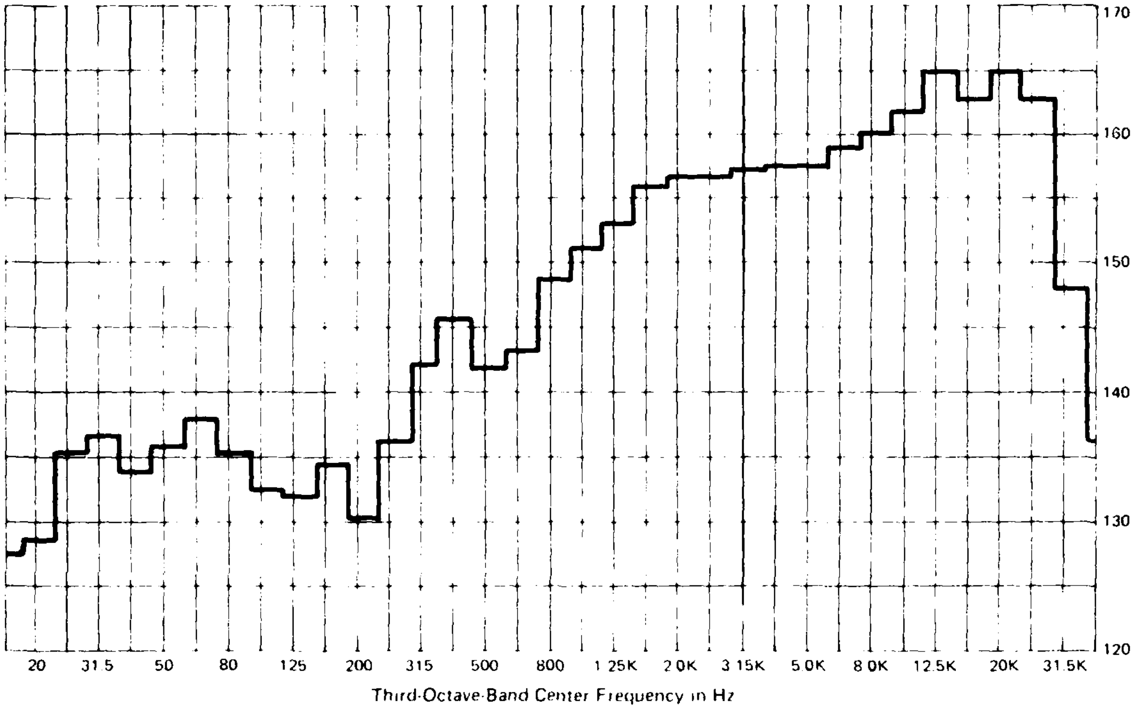

FIGURE 20 AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER-OPERATED STANLEY ROCK DRILL, HD 45, ON CONCRETE, HYDROPHONE 6 FEET FROM TOOL

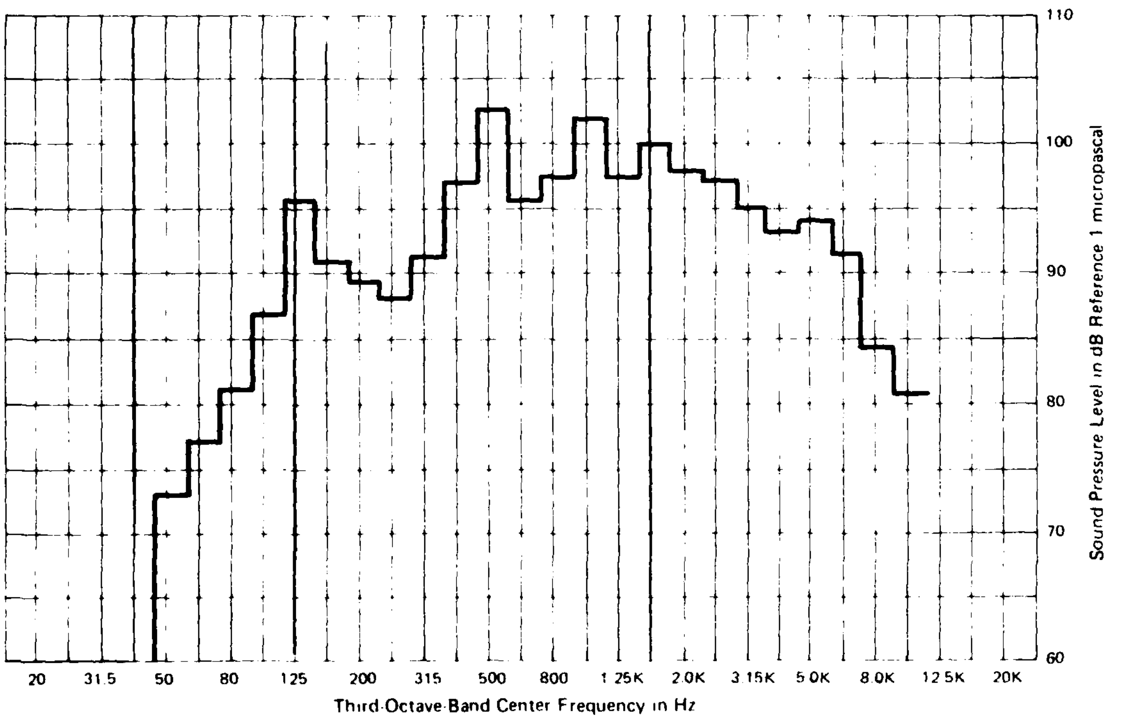

FIGURE 21 AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER IN A MK 12 HELMET OPERATING A STANLEY ROCK DRILL, HD 45, ON CONCRETE

Underwater Noise Measurement Results

The tests which were analyzed are listed in Table 7. The data are presented in Figures 20 and 21.

STANLEY HYDRAULIC SINKER DRILL, MODEL SK58, TYPE 110

Technical Description

The Stanley hydraulic sinker drill model SK58, Figure 22, is designed for use in utility pole construction, blast hole drilling, gas line probing and demolition work. The model SK58 drills 1 inch to 3 inch diameter holes up to 20 feet deep in rock or concrete. It uses air or water to flush all rock particles from within drilled holes. The rotational rate of the model SK58 is adjustable from 0 to 300 revolutions per minute. The drill has direct drive rotation and the rotation rate is independent of the impact rate of up to 2500 blows per minute. The starting system incorporates a feathering valve for a fast startup. This particular model SK58 sinker drill utilizes no gear box. A summary of the rock drill characteristics is listed in Table 8.

Table 8. Rock Drill Characteristics Model SK58, Type 110

Characteristic	Description
Capacity	4-1/4" Shank x 1" Hex
Weight	67 lbs.
Length	26 in.
Width	18 in.
Pressure	1500-2000 psi
Flow Range	7-9 gpm
Optimum Flow	9 gpm
Porting	1/2" SAE (Hyd) 1/2" NPT (Air)
Hose Whips	Yes(Hyd) Yes(Air/Water)
Connect Size and Type	1/2" male pipe hose end (Hyd) 3/8" male pipe hose end (Air/Water)
Hyrevz Motor	Integral

Laboratory and Land Test Results

The operating characteristics of the drill measured during the laboratory testing are listed in Table 9. Unlike the HD20 and HD45 models, there was no apparent correlation between flow rate and stall pressure. Similarly, there was no apparent correlation between valve setting and rotational rate, so it was necessary to use actual revolutions per minute as the indicator. The maximum torque, corresponding to a flow rate of 9 gallons per minute, was 35 foot-pounds.

The laboratory and land tests were conducted using 20 foot long hydraulic hoses. The tests in water utilized lengths of 250 feet.

Before the tests were completed, it was discovered that the accumulator had not been charged during the testing. Selected procedures were repeated with the accumulator charged to determine its effect.

Flow rates of 7, 8 and 9 gallons per minute were tested using a drill bit diameter of 2-1/4 inches with the accumulator charged and uncharged.

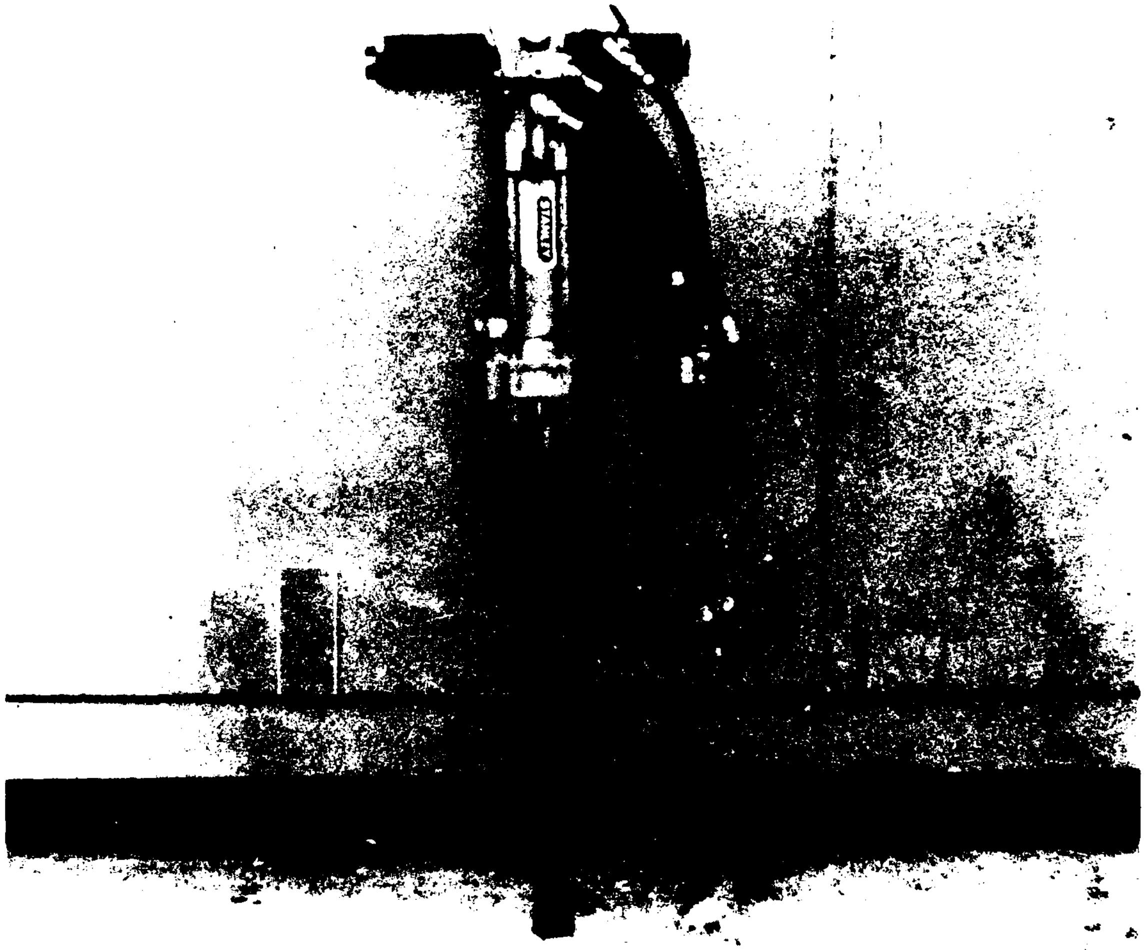

FIGURE 22 **MODEL SK 58 DRILL**

Table 9. Operating Characteristics of Model SK58 as Measured during Laboratory Tests

Flow Rate (GPM)	Running Pressure (PSI)		Stall Pressure (PSI)		Number of Valve Turns	Impact Frequency (Hz)
	High	Low	High	Low		
10.34	1625	200	2375	450	1	25.50
5.06	550	75	-	275	1	22.13
6.44	725	75	1825	475	1	23.40
7.70	950	125	2125	450	1	23.25
9.88	1525	150	2375	425	1	23.88
			RPM			
4.88	1525	175	180		1	23.00
9.88	1550	200	510		0	24.00
8.96	1300	175	495		0	23.40
7.70	975	100	325		0	21.60
6.55	800	75	275		0	20.25

The results, presented in Figure 23, indicated that for both cases the drilling rate steadily increases with flow rate. The manufacturer's recommended maximum flow rate, 9 gallons per minute, was selected as the optimum value. The differences in drilling rates for the accumulator charged and uncharged using a variety of drill bit diameters is illustrated in Figure 24.

The drilling rate was measured with various rotational rates using a drill bit diameter of 2-1/4 inches and a flow rate of 9 gpm. The optimum value for the uncharged condition was selected as 60 revolutions per minute. Based on curve for the charged accumulator case in Figure 25, 100 revolutions per minute was selected as the optimum value. In addition to the greater penetration rate, this speed was characterized by ease of handling.

The optimum bearing load was also determined with the accumulator charged and uncharged. With a flow rate of 9 gpm and essentially constant rotational rates, data were collected with 2 and 2-1/4 inch diameter drill bits. The drilling rates, plotted in Figure 26, increase with increasing bearing load. Larger weights caused difficulty in handling the drill, so 30 pounds was selected as the optimum value.

Shallow and Deep Water Test Results

The tests in shallow water were run with the accumulator charged and uncharged. The cases were run at their respective optimum rotational rates of 100 and 60 rpm. The flow rate was held at 9 gpm, and 30 pound and zero added weights were tested with four drill bit diameters. The results are shown in Figure 27.

In deep water, zero and 30 pound added weights were tested on the drill with the accumulator charged. The resulting drilling rates, shown in Figure 28, were similar to those measured during the shallow water tests.

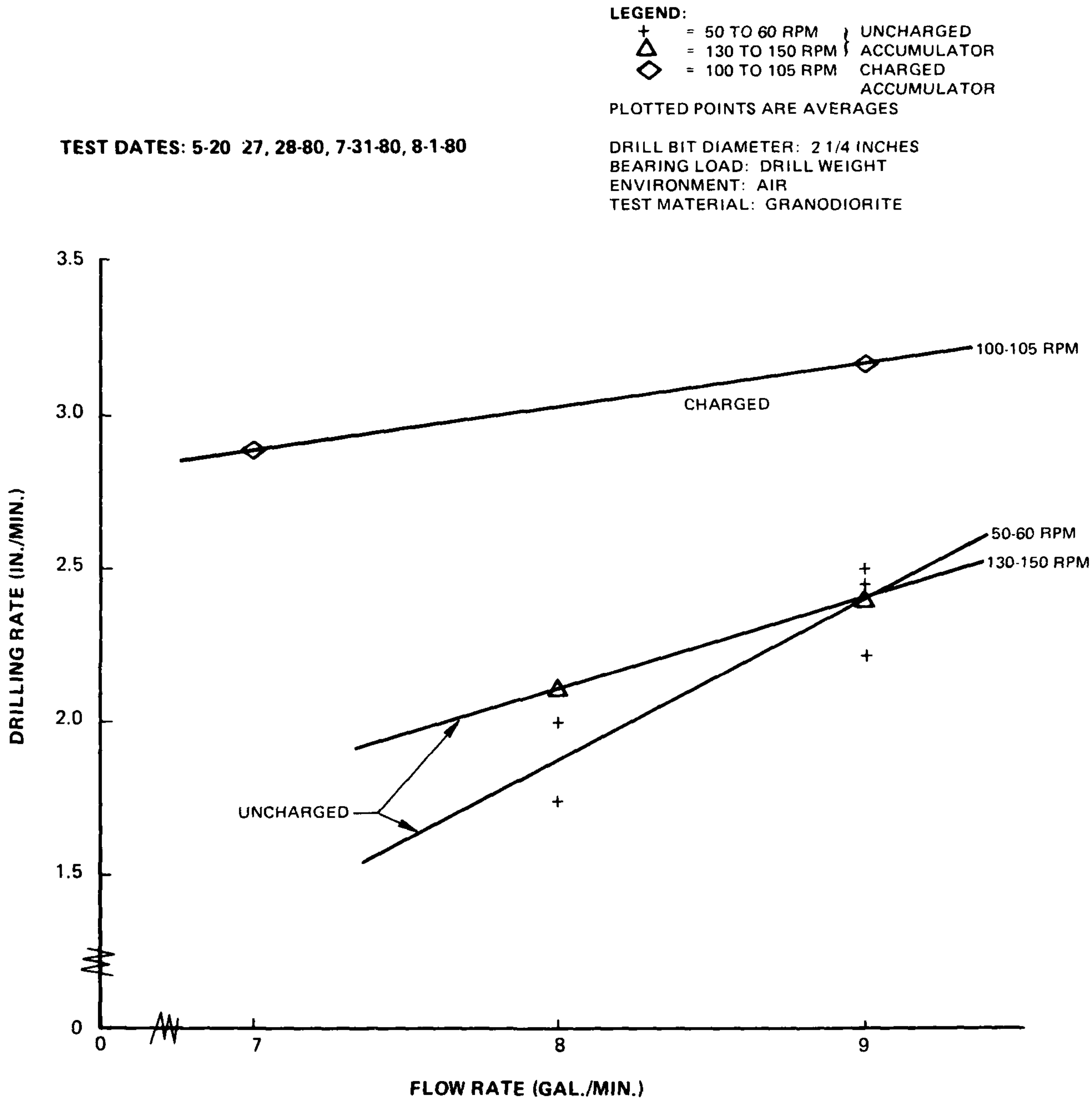

FIGURE 23 –**DRILLING RATE VERSUS FLOW RATE FOR THE SK 58 LAND TEST FOR DETERMINING THE OPTIMUM FLOW RATE WITH THE ACCUMULATOR CHARGED AND UNCHARGED**

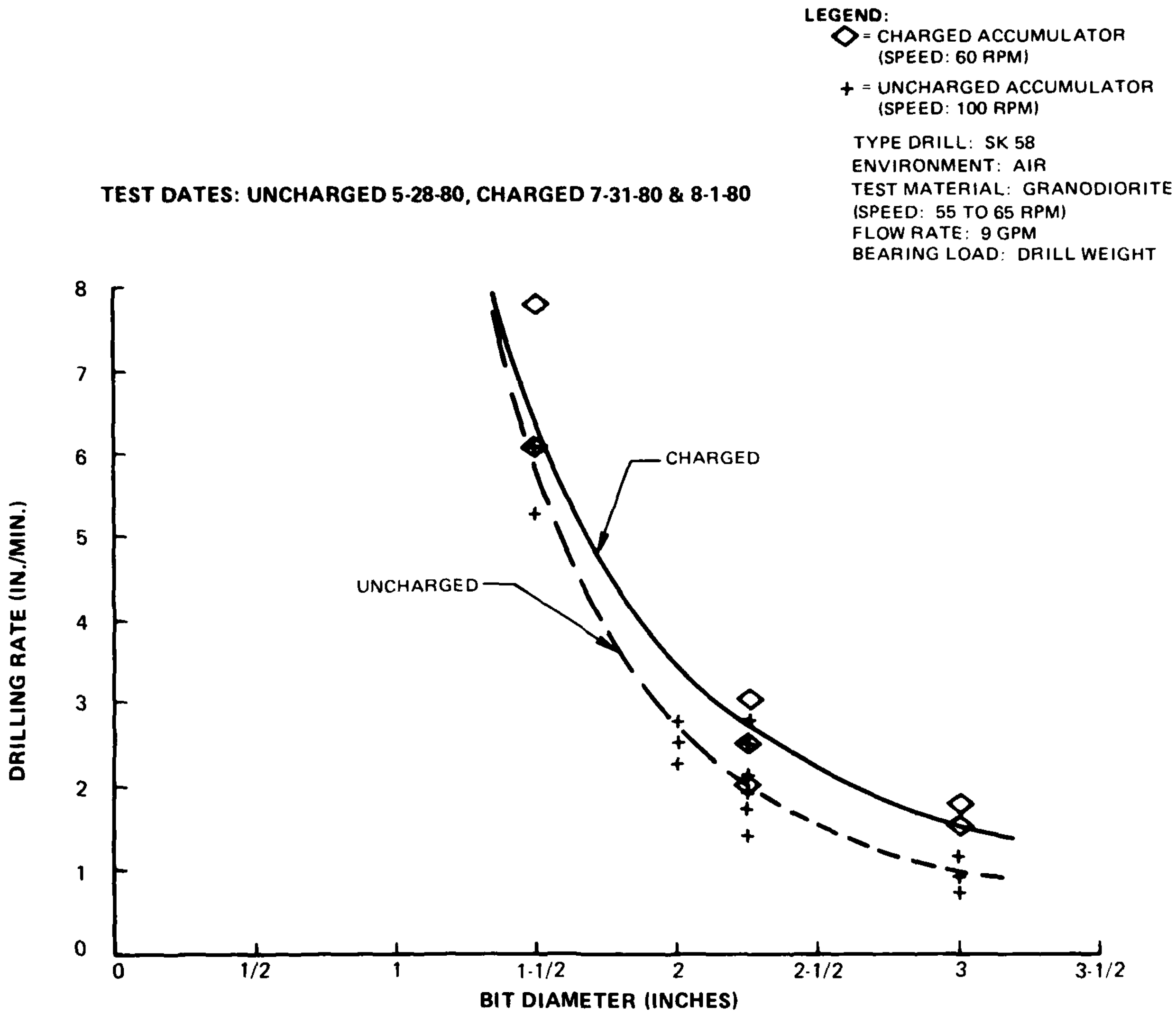

FIGURE 24 – DRILLING RATE VERSUS BIT DIAMETER FOR THE SK 58 LAND TEST FOR DETERMINING THE DIFFERENCES BETWEEN OPERATING WITH THE ACCUMULATOR CHARGED AND UNCHARGED

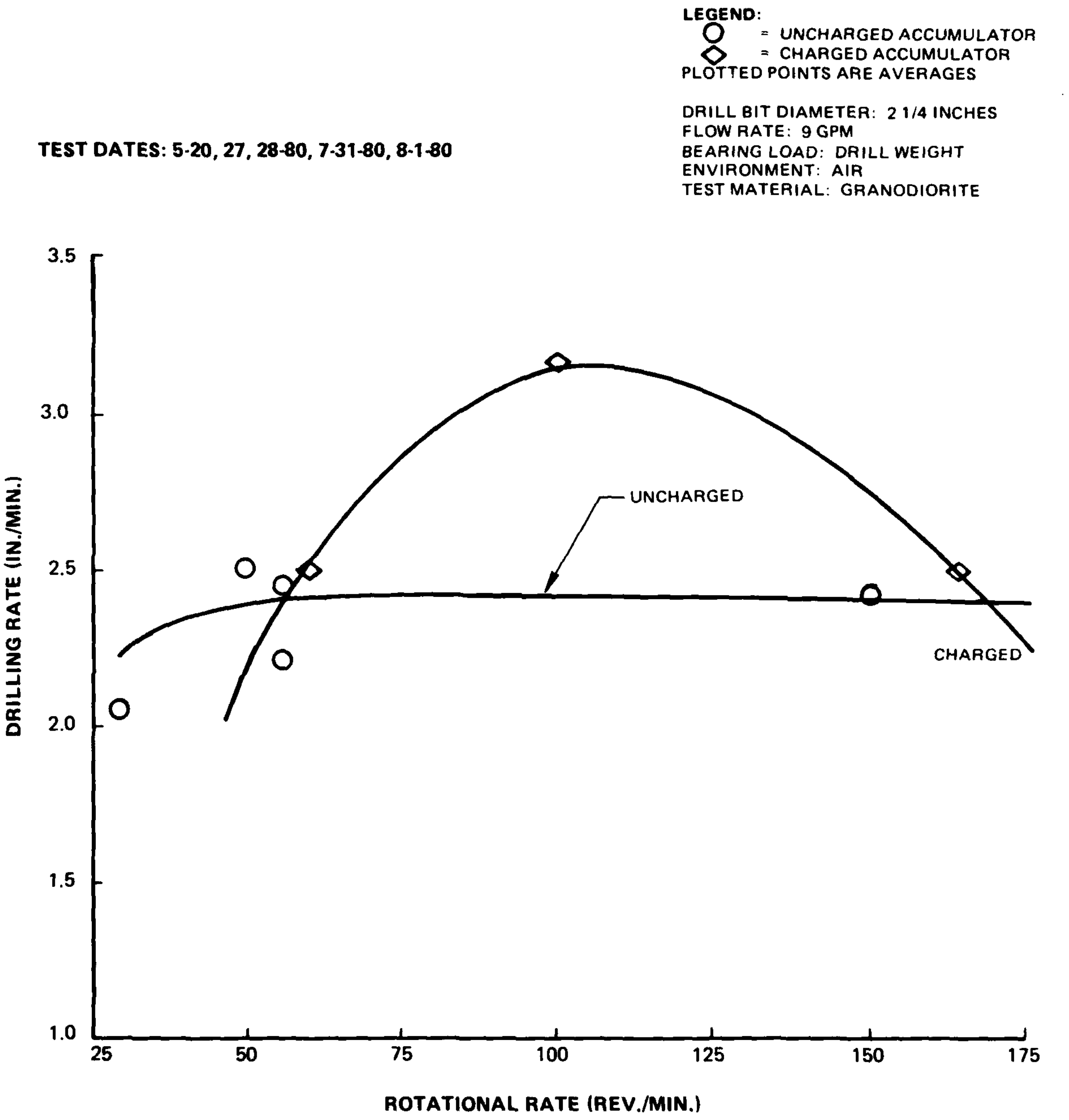

FIGURE 25 DRILLING RATE VERSUS ROTATIONAL RATE FOR THE SK 58 LAND TEST FOR DETERMINING THE OPTIMUM ROTATIONAL RATE WITH THE ACCUMULATOR CHARGED AND UNCHARGED

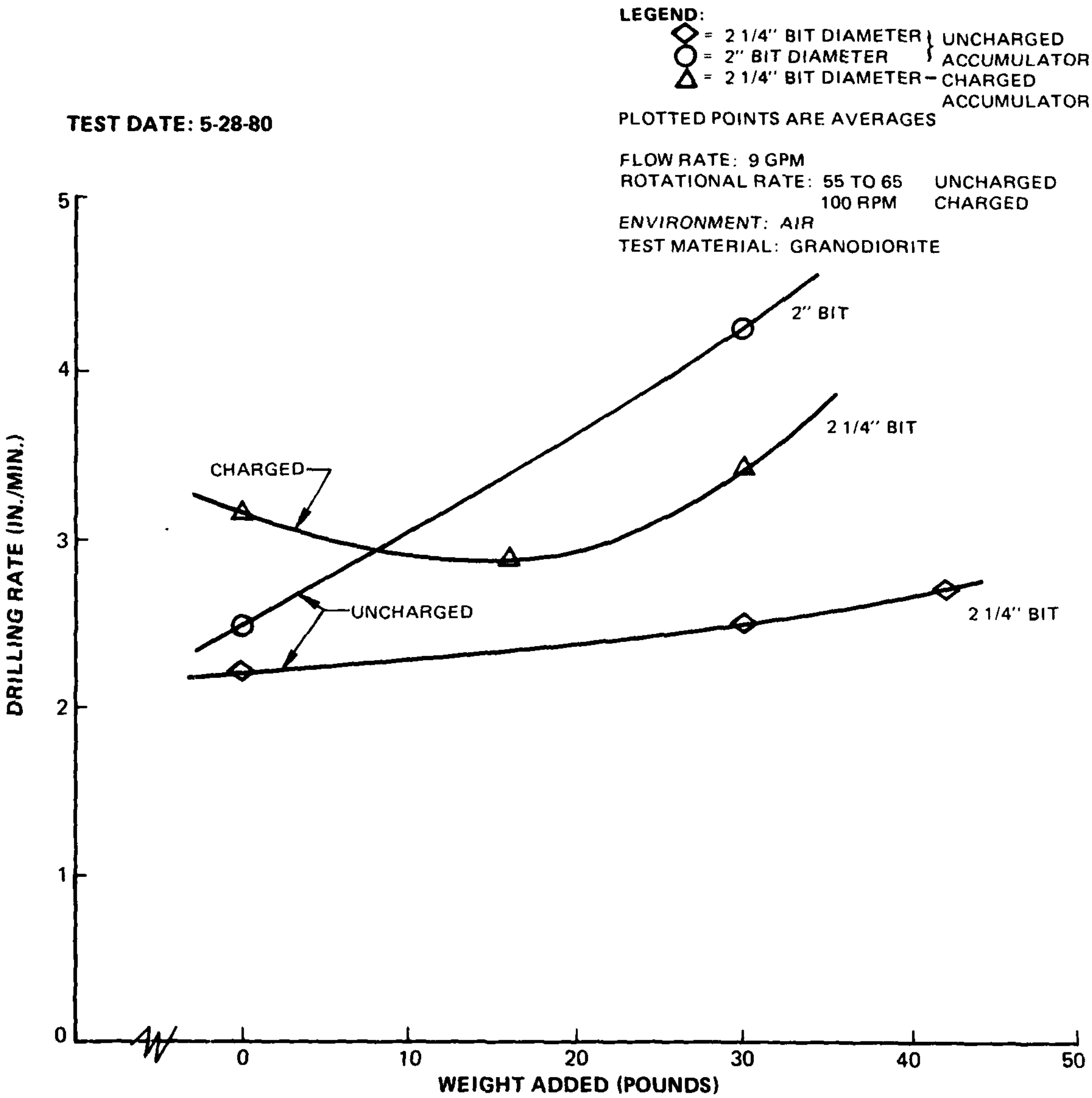

FIGURE 26 **DRILLING WEIGHT VERSUS WEIGHT ADDED FOR THE SK 58 LAND TEST FOR DETERMINING THE OPTIMUM BEARING LOAD WITH THE ACCUMULATOR CHARGED AND UNCHARGED**

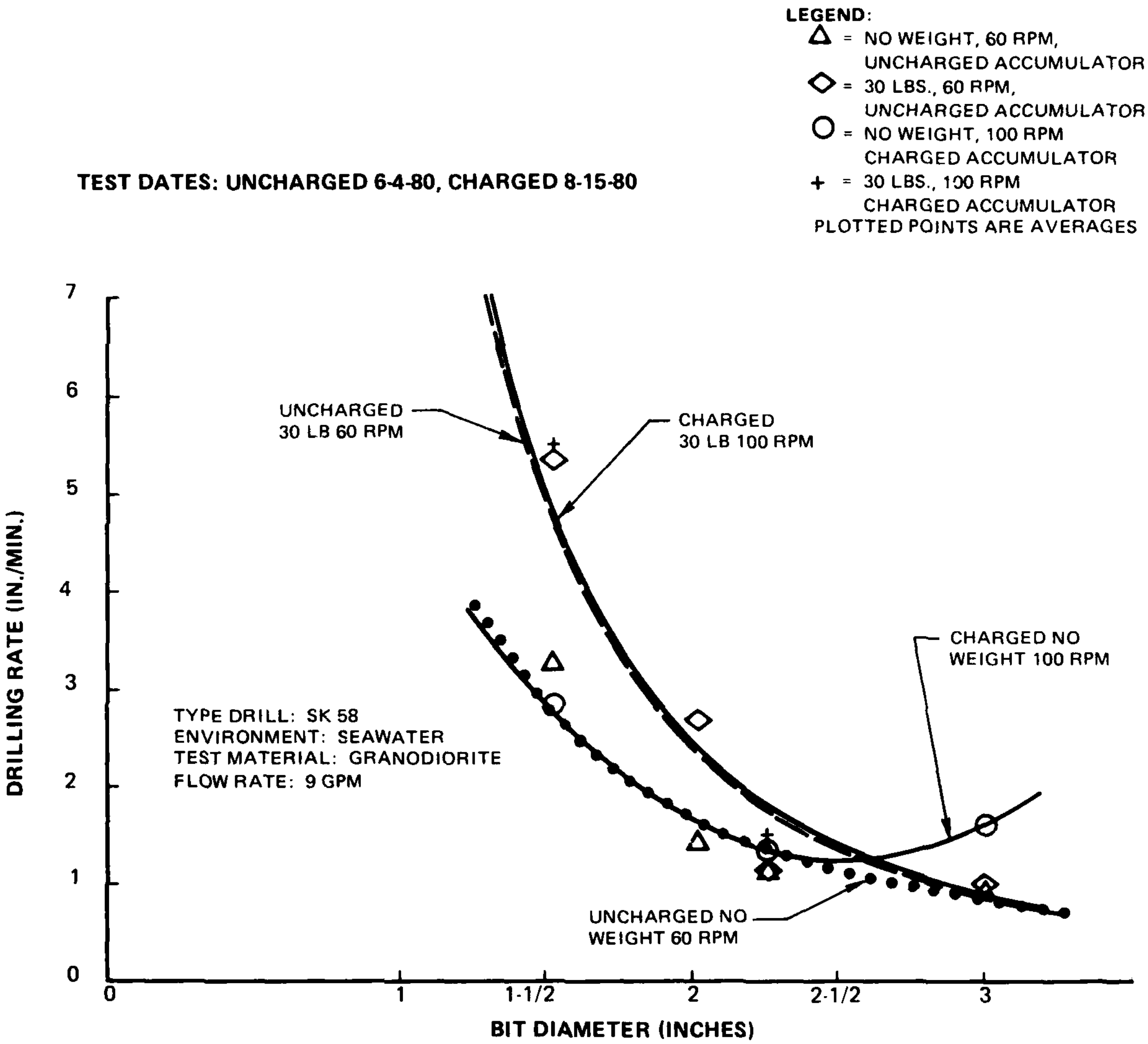

FIGURE 27 **DRILLING RATE VERSUS BIT DIAMETER FOR THE SK 58 TANK TEST FOR DETERMINING THE EFFECT OF VARYING BEARING LOAD AND OF CHARGED AND UNCHARGED ACCUMULATOR ON THE DRILLING RATE IN SHALLOW WATER**

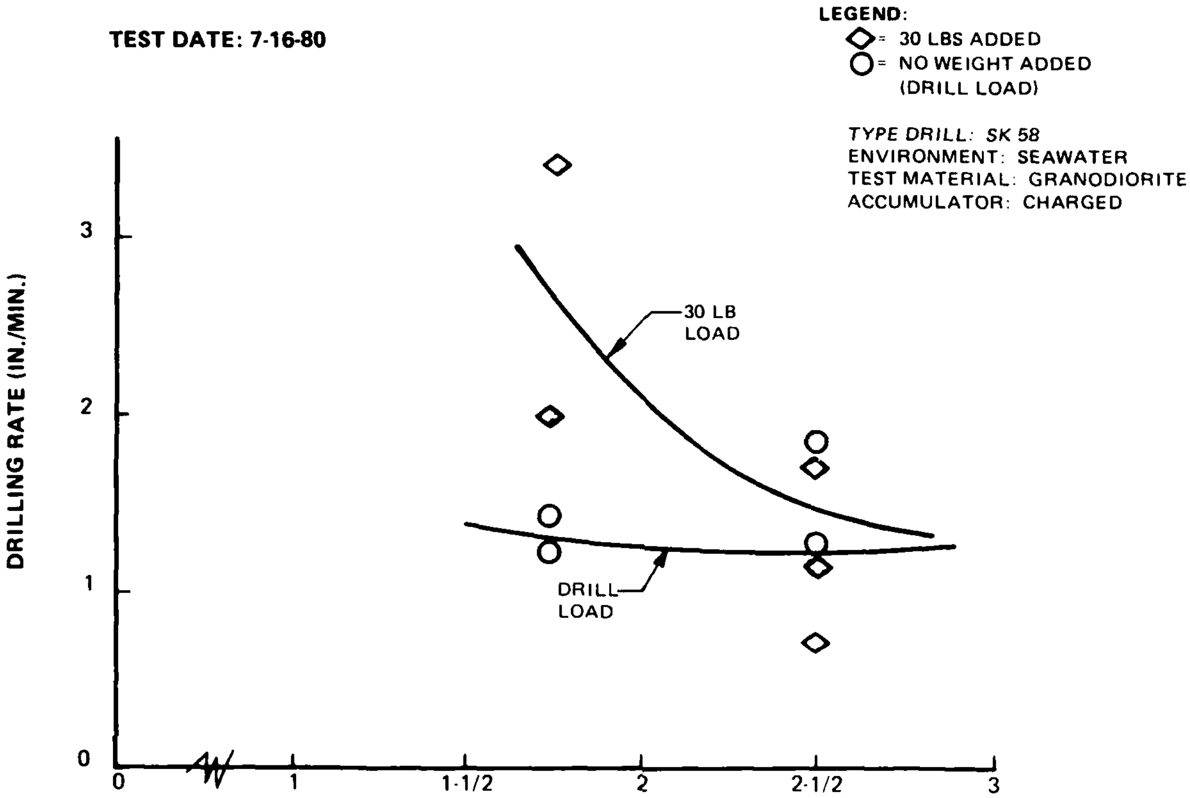

FIGURE 28 -DRILLING RATE VERSUS BIT DIAMETER FOR THE SK 58 DEEP WATER TEST FOR DETERMINING THE EFFECT OF BEARING LOAD IN DEEP WATER

Table 10. Noise Measurement Tests of Stanley Rock Drill, SK58

Drill Bit Diameter Inches	Hydrophone Location	Hydrophone Overall Sound Pressure Level Ref: 1 Micropascal	Microphone in MK 12 Helmet Location	Microphone Overall Sound Pressure Level Ref: 0.000204 dynes/cm^2 (A-weighted)
1	at diver's ear	178		
1	at diver's ear, wet suit protected	161		
1	6 feet from tool	174	4 feet from tool	84

The divers found this drill more difficult to handle than the other two models, primarily due to its increased size and weight. The control lever, located on the drill body rather than on the handle, could not be reached without letting go with one hand. Use by a team of two divers is a solution to both these difficulties.

Reliability and Maintainability Test Results

Dismantling of the drill following the underwater tests revealed two areas of corrosion. Pitting was evident on the lower 3/4 inch of the piston and in the area between the drive motor and control block seals.

Underwater Noise Measurement Results

The tests which were analyzed are listed in Table 10. The data are presented in Figures 29 and 30.

CONCLUSIONS AND RECOMMENDATIONS

Stanley Hydraulic Hammer Drill, Model HD20

As a result of the measurements made during the laboratory and land tests of the model HD20 drill, the following operating conditions were established as those resulting in the greatest penetration (drilling) rates:

Hydraulic fluid flow rate	8 gallons/minute
Drill rotational rate	That corresponding to a valve setting of 1/2 turn from the fully open position
Bearing load	48 pounds in addition to the tool weight

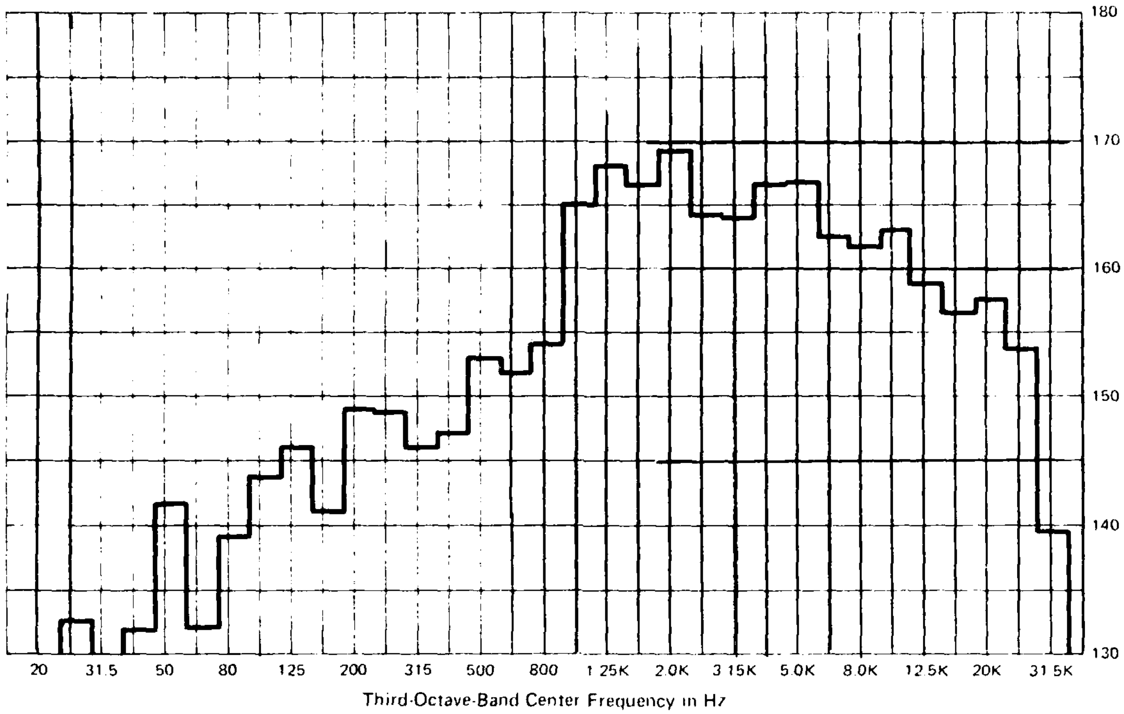

FIGURE 29 **AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER-OPERATED STANLEY ROCK DRILL, SK 58, HYDROPHONE 6 FEET FROM TOOL**

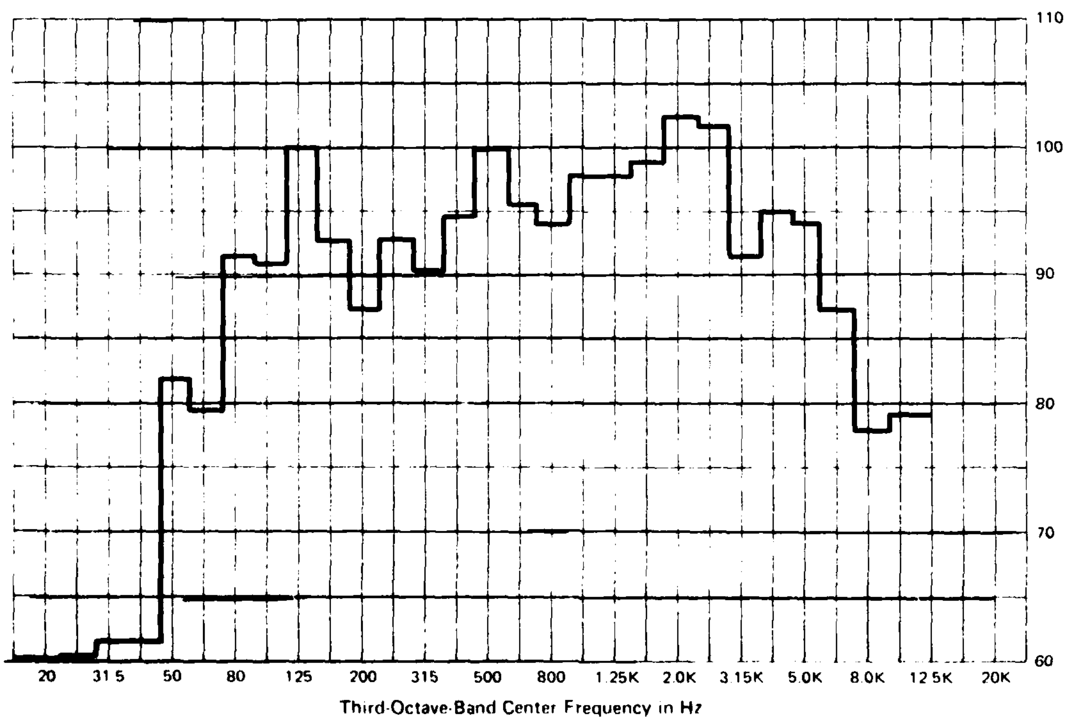

FIGURE 30 **AVERAGE SOUND PRESSURE LEVEL SPECTRUM FOR A DIVER IN A MK 12 HELMET OPERATING A STANLEY ROCK DRILL, SK 58**

The shallow and deep water tests also indicated that 48 pounds was the optimum added bearing load. With the drill operating at the optimum conditions listed above, the drilling rates in water were:

Bit Size	Penetration Rate (Avg)
1/2"	7.9 inches/minute
1"	5.1 inches/minute
1-1/2"	0.8 inch/minute

The results for this and the two other models are presented in Figure 31.

The underwater noise measurements resulted in the average overall sound pressure levels expected to be experienced by divers with various equipment and the proposed time limits for use of the tool presented in Table 11.

Based on these results, it is recommended that when using this tool a wet suit hood be worn.

The divers indicated that the model HD20 drill was easy to handle and control while the removal of the trigger locking mechanism allowing "deadman" operation to occur is recommended. Cleaning of the drill is recommended after each use due to water found in the gear casing and pitting that had occurred on the piston.

Based on the results of these tests, evaluation of the drill by NCEL, subject to the wearing of a wet suit hood, and following removal of the trigger locking mechanism, the model HD20 drill is judged safe and adequate for Navy diver use when operated in accordance with current NAVSEA procedures.

Stanley Hydraulic Hammer Drill, Model HD45

As a result of the measurements made during the laboratory and land tests of the model HD45 drill, the following operating conditions were established as those resulting in the greatest penetration (drilling) rates:

Hydraulic fluid flow rate	9 gallons/minute

Table 11. Model HD20 Sound Pressure Levels and Operating Time Limits

Diver	Overall Sound Pressure Level - Ref 1 Micropascal	Overall Sound Pressure Level - Ref 0.000204 dynes/cm^2	Proposed Time Limit
SCUBA no wet suit	175	98	3 hours
SCUBA with 1/4 inch wet suit hood	163	86	over 8 hours
MK 12	111	85	over 8 hours

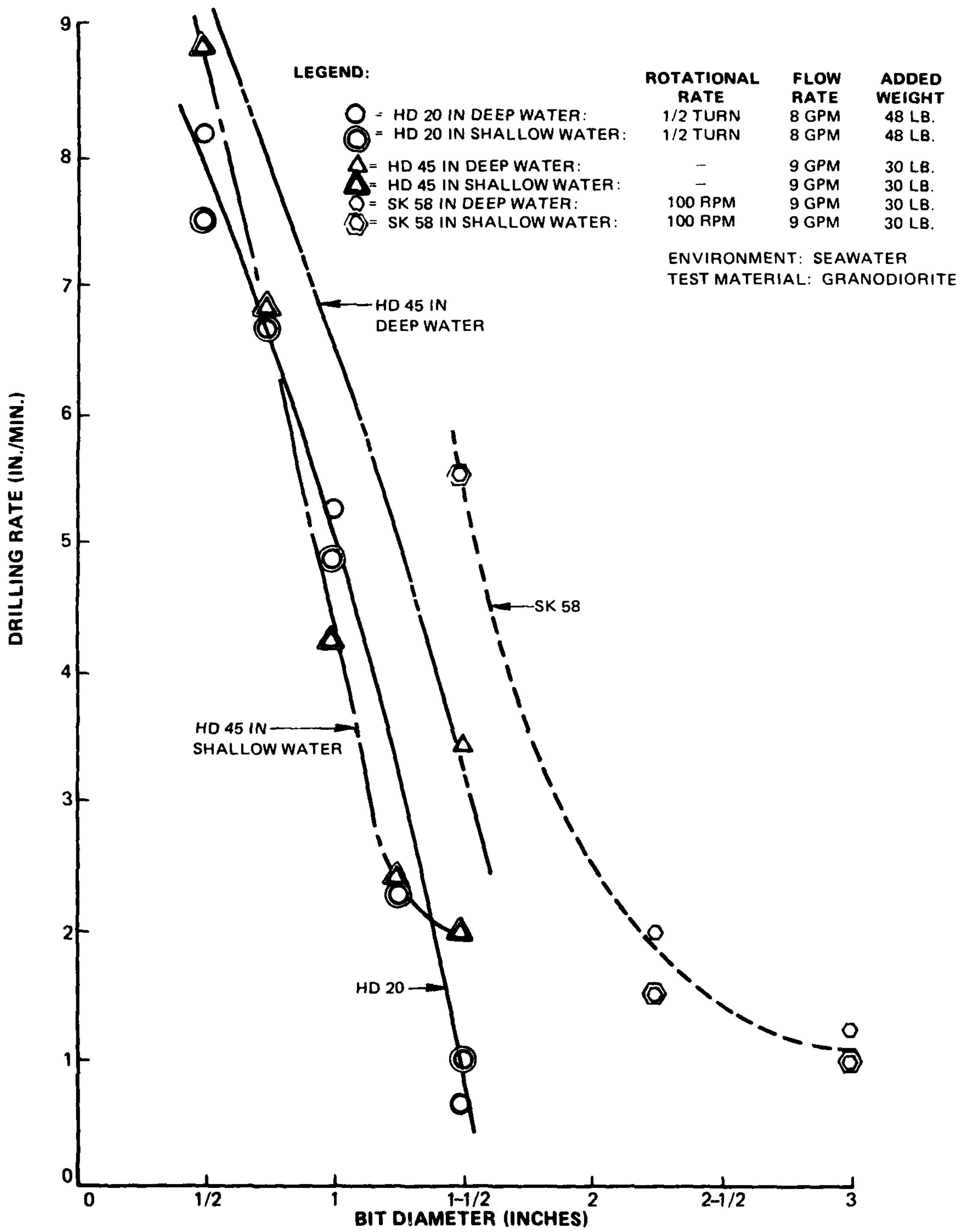

FIGURE 31 —DRILLING RATE VERSUS BIT DIAMETER FOR THE THREE DRILLS AT OPTIMUM ROTATIONAL RATE, FLOW RATE AND BEARING LOAD IN SEAWATER

Bearing load	54 pounds in addition to the tool weight

In shallow and deep water, the optimum added bearing load was reduced to 30 pounds, primarily to improve tool handling. With the drill operating at the in-water optimum conditions, the drilling rates under water were:

Bit Size	Avg. Penetration Rate (inches/minute) Deep	Shallow
1/2"	9.3	8.9
1"	6.6	4.4
1-1/2"	3.4	2.0

The results for this and the other two models are presented in Figure 31.

The underwater noise measurements resulted in the average overall sound pressure levels expected to be experienced by divers with various equipment and the proposed time limits for use of the tool presented in Table 12.

Based on these results, it is recommended that when using this tool a wet suit hood be worn.

The divers gave favorable evaluations of the model HD45 rock drill. It is recommended that the tool be cleaned after each use in water.

Based on the results of the tests and evaluation of the drill by NCEL, and subject to the wearing of a wet suit hood, the model HD45 drill is judged safe and adequate for Navy diver use when operated in accordance with current NAVSEA procedures.

Stanley Hydraulic Sinker Drill, Model SK58, Type 110

As a result of the measurements made during the laboratory and land tests of the model SK58 drill, the following operating conditions were established as those resulting in the greatest penetration (drilling) rates:

Table 12. Model HD45 Sound Pressure Levels and Operating Time Limits

Diver	Overall Sound Pressure Level - Ref 1 Micropascal	Overall Sound Pressure Level - Ref 0.000204 dynes/cm^2	Proposed Time Limit
SCUBA no wet suit	174	97	3 hours
SCUBA with 1/4 inch wet suit hood	162	85	over 8 hours
MK 12	-	84	over 8 hours

Table 13. Model SK58 Sound Pressure Levels and Operating Time Limits

Diver	Overall Sound Pressure Level - Ref 1 Micropascal	Overall Sound Pressure Level - Ref 0.000204 dynes/cm^2	Proposed Time Limit
SCUBA no wet suit	178	101	1-3/4 hours
SCUBA with 1/4 inch wet suit hood	161	84	over 8 hours
MK 12	-	84	over 8 hours

Hydraulic fluid flow rate	9 gallons/minute
Drill rotational rate	100 revolutions/ minute
Bearing load	30 pounds in addition to the tool weight

The shallow and deep water tests confirmed 30 pounds as the optimum added bearing load. With the drill operating at the optimum conditions listed above and with the accumulator charged, the drilling rates in water were:

Bit Size	Penetration Rate (Avg)
1-1/2"	5.5 inches/minute
2-1/4"	1.8 inches/minute
3"	1.1 inches/minute

The results for this and the other two models are presented in Figure 31.

The underwater noise measurements resulted in the average overall sound pressure levels expected to be experienced by divers with various equipment and the proposed time limits for use of the tool presented in Table 13.

Based on these results, it is recommended that when using this tool a wet suit hood be worn and no time limit be imposed.

Due to the unit weight and remote location of the trigger mechanism from the tee handle, model SK58 operating procedures must require handling by two divers.

Based on the results of these tests and evaluation of the drill by NCEL, and subject to the two-diver operating requirement and wearing of a wet suit hood, the model SK58 drill is judged safe and adequate for Navy diver use when operated in accordance with current NAVSEA procedures.

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LIST OF SYMBOLS

A	Area (in.^{2})
D	Drill bit diameter (in.)
E_D	Energy output of drill (in.-lb.)
E_I	Impact energy (in.-lb.)
E_R	Energy required to remove a unit volume of rock (in.-lb.)
e	Energy transmission efficiency
f	Impact frequency (impacts/min.)
K	Drilling rate constant
P_r	Penetration rate (in./min.)
t	Time
V	Volume of rock removed (in.^{3})

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